This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

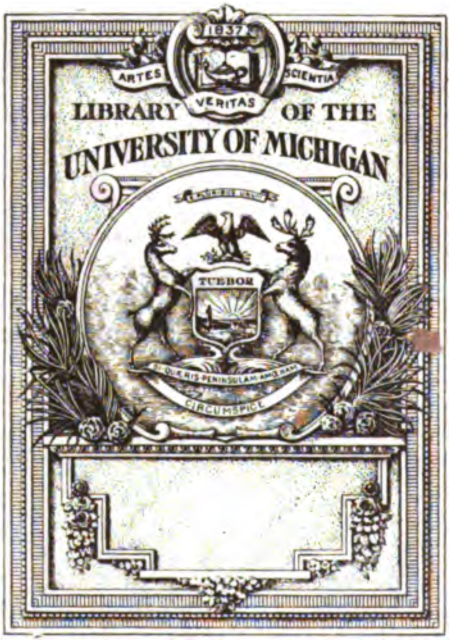
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`


1837
ARTES
SCIENTIA
VERITAS
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
E PLURIBUS UNUM
TUEBOR
SI QUAERIS PENINSULAM AMOENAM
CIRCUMSPICE

BY THE SAME AUTHOR

COLOR
AND ITS
APPLICATIONS

---

360 Pages. 129 Illustrations. 4 color plates. Net $3.00

Rembrandt
(Courtesy of the Metropolitan Museum of Art)

Rembrandt
(*Frontispiece*)

LIGHT AND SHADE

AND THEIR APPLICATIONS

BY

Matthew. LUCKIESH

PHYSICIST, NELA RESEARCH LABORATORY
NATIONAL LAMP WORKS OF GENERAL ELECTRIC COMPANY

135 Illustrations—10 Tables

> "O first created beam and thou great Word
> 'Let there be light, and light was over all.'
> Why am I thus bereaved thy prime decree?"
>
> MILTON

NEW YORK
D. VAN NOSTRAND COMPANY
25 Park Place
1916

THE · PLIMPTON · PRESS
NORWOOD · MASS · U · S · A

PREFACE

Inspired by a conviction that there is much more to the art and science of lighting than is commonly practised, I began, several years ago, a study of the appearances of objects. Attention was naturally directed toward those factors which influence light, shade, and color, because vision is accomplished through the distinction of differences in brightness and color. In other words, the aim throughout the study has been to unearth the fundamentals of lighting. It early became evident that the problem of lighting, as affecting the appearances of objects, could be divided into two parts, namely, the considerations of the quality and of the distribution of light. The former chiefly affects color and the latter, light and shade. Color has been treated in a separate volume and, insofar as lighting, vision, and the appearances of objects are concerned, this book is a companion to the preceding one. It has been difficult to transmit to others much of the data that have been garnered from observations and experiments. One of the greatest difficulties is encountered in illustrating the discussions, owing to the extreme limitations of the photographic process as compared with the eye — the recording apparatus of prime importance in the study of light and shade as attempted here. I am unaware of the existence of any treatise in which a general analytical discussion of light and shade has been presented, therefore I believe this book will be helpful in many arts. The esthetic side of the subject is touched upon usually for the purpose of illustrating the usefulness of a knowledge of the science of light and shade. The esthetic problem is, as a whole, indeterminate, because it involves individual taste. However, every art must have a scientific foundation, consisting of indisputable facts unrelated to individual taste, and it has been the aim in the preparation of this book to supply at least the skeleton of this foundation for the applications of Light and Shade.

It is a pleasant duty to acknowledge my indebtedness to the management of the National Lamp Works of the General Electric Company, to whom the Nela Research Laboratory and its attendant opportunities owe their existence, to Dr. E. P. Hyde, director of the laboratory, for facilities so generously provided for prosecuting this and other work, and to others who have aided in various ways.

M. LUCKIESH

February 21, 1916

TABLE OF CONTENTS

CHAPTER I

Page

INTRODUCTION 1

The importance of light and shade in vision and in many arts.

CHAPTER II

THE CHARACTERISTICS OF OBJECTS 7

Light. Chromatic and achromatic sensations. Reflecting power. Selective and non-selective reflection. Brightness. Simple optical laws. Types of reflection and transmission. Table of reflection coefficients. High-lights. Specular and diffuse reflection coefficients of objects related in a table.

CHAPTER III

THE SHADOW. 22

The shadow differentiated from the cast shadow. Light models form. A sphere and a disk under various lightings. Comparisons of a hollow and a solid hemisphere. Shadows on geometrical objects caused by different light sources. Character of the high-light influenced by brightness and shape of the light source. Light and shade on various objects having curved and plane surfaces.

CHAPTER IV

THE CAST SHADOW 33

Cast shadow compared with the shadow. Formation of shadows as influenced by small and large objects and by the solid-angular extent of light source. Other geometrical relations. Effect of diffused or scattered light. Influence of reflection coefficient of surroundings. Shadows reenforce each other. Brightness of cast shadow and the reflection coefficient of the receiving surface. Shape of cast shadow and the shape of the receiving surface. Effect of large and small light sources. Apparatus for studying cast shadows. Effect of various light sources and other factors on the cast shadows. Multiple shadows. Patterns obtained very simply by overlapping shadows.

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

medium upon the light and shade. Glazed objects. Marble. Dull and polished bronze. Discussion of the fitness of the medium. Relief approaches drawing. Freaks of lighting. Lighting sculpture exhibits. Alcoves. Solid angle subtended by skylights and windows. Arranging sculpture in a gallery. Sculpture galleries.

CHAPTER IX

A special field of sculpture. Co-operation of lighting expert, decorator, and architect. Importance of Nature's lighting. Light and shade not fixed. Lighting factors. Character of surfaces. Capital under different lightings. Effect of variation in distribution of natural light. Moldings under different lightings. Other decorative pieces. What the imagination supplies. High-lights. Diffused and direct light. Position of lighting units. Illumination and brightnesses. Exterior lighting. Flood-lighting. Lighting a great aid to the architect. See last Chapter.

CHAPTER X

The illusion of solid objects. Three viewpoints, namely appearance of objects, the process of making the picture, and the final record. The artist is a link between two lightings. Painting is the expression of impressions. Limitations of pigments. Neutral and colored pigments. Effect of illuminant on values. Visible spectrum. Analysis of values in paintings. Nature cannot be copied with pigments. Illusions. Shadows an aid in expressing mood. The artist must be an analyst. Lighting of paintings. Unequal distribution of light on paintings. Accentuating contrast.

CHAPTER XI

Relation of play, setting, and lighting. The modern movement in the theatre. Footlights produce grotesque appearances of faces. Defects of painted shadows and perspective. Importance of light distribution in affecting the mood of a given setting. Modern accessories. Possibilities of expression in light, shade, and color. Shadows should be real.

CHAPTER XII

Photographic image in light and shade. Negative. Positive. True values seldom realized in practise. Photochemical and visible radiation not identical in general. Spectral sensibilities of various classes of emulsions compared with that of the eye. No commercial plates in general record true values unaided. Ordinary, orthochromatic, and panchromatic emulsions. Filters. Limitations of the photographic emulsion. Gradation or contrast range of emulsions. Transparency, opacity, and density of silver deposit. Relation between exposure and density. Contrast range reproducible in practise. Experiment showing the limited contrast range attainable. Effect of development on gradation. Actinicity of sunlight and skylight. Lighting in photography. Reproduction of light and shade effects is chief aim of photography. Posing and lighting. Profitable study of masterpieces of art. Lighting and the subject. Styles of lighting. Portraiture and sculpture. Fundamentals of lighting in portraiture. Advantage of portable artificial lighting units. Reflecting screens. Examples of artificial lighting effects.

CHAPTER XIII

Recognition of objects. Visual acuity or the perception of fine detail. Brightness sensibility or the minimum perceptible brightness difference. Extraordinary range of sensibility of the eye. Table of approximate brightness sensibilities. Growth and decay of visual sensation. Retinal adaptation. Objectionable contrasts. Brightness contrasts ordinarily experienced. Limitations of pigments and the photographic process. Brightness sensibility of retina and the design of lighting systems.

CHAPTER XIV

The development of the lighting expert. Other chapters contribute material for the lighting expert. Light and shade from the utilitarian viewpoint. Eye comfort. Maximum brightness desirable. Maximum contrast desirable. Uniformity of illumination. Visualizing the results of proposed installations. Lighting systems. Diffused light. Scattered light. Various assumed conditions treated graphically for the purpose of visualization. A point source. Effect of reflection coefficient of surroundings. Two light sources a given distance apart. Variation of relative horizontal and vertical illuminations with height of light source. Variation of maximum and minimum illumination with heights of two sources and their distance apart. Complete analysis of illumination conditions between two units a given distance apart. Relation of upward and downward light for natural and artificial interior lightings. Relation of lighting to the light and shade of architecture and decoration. Symmetry in lighting effects. Lighting effects should harmonize with architectural patterns. Distribution of light affects the general impression of an interior. Various examples of interior lighting.

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIGHT AND SHADE
AND THEIR APPLICATIONS

CHAPTER I

LIGHT AND SHADE

INTRODUCTION

Vision is accomplished through the ability to distinguish differences in light, shade, and color. If the image of any scene which is focused upon the retina could be examined it would appear only as a miniature map of varied colors and brightnesses similar to that seen on the focusing screen of a camera. However, there is an important difference between the records made by the eye and by the camera. In the case of the eye only the portion of the image near the optical axis is seen in true focus, but the camera faithfully focuses the images of objects included in a relatively large solid angle. The difference between the records obtained through the eye and camera respectively is further accentuated by the presence of physiological and psychological phenomena in the human visual process.

The analysis of human consciousness reveals two kinds of visual sensations, namely, colored and colorless, or chromatic and achromatic sensations. No masterpiece of painted or sculptured art or no beautiful natural landscape, as far as the visual sense is concerned, consists of more than an arrangement of varied colors and brightnesses. In general, color plays a subordinate part in vision relative to light and shade.

The magical drapery of color, which is omnipresent although usually unnoticed, would disappear in the absence of the gift of color vision. Indeed, color vision appears to be a gift — the Creator's full measure — because color-blind persons progress almost unhampered excepting in certain fields where man has called upon color to serve him. These persons appear to derive much pleasure from their surroundings and, doubtless, never fully realize their deficiency. Few persons observe the exact hue of an object unless the patch of color is large. In fact Nature's many greens are simply green to most persons. However, the forms of objects, which are almost always molded by light and shade, are usually quite apparent to them. That is, differences in hue are less conspicuous than differences in light and shade; in other words, light and shade provide the skeleton and body of a scene, and the colors supply the drapery.

It is not the intention to depreciate the importance of color in vision, because it is recognized that the presence of colors and the physiology and psychology of color vision are of extreme importance in our daily life. It is merely unfortunate that the lack of development of observation and appreciation of color by the human race as a whole has forced color to play a minor role in ordinary vision, notwithstanding it is ever ready to furnish pleasure and interest by its continual variation in Nature.

This book is largely a result of a study of the fundamentals of lighting and vision. Inasmuch as the subject of color has been treated in a previous volume[1] it will not be treated extensively here. However, it is difficult to exclude the consideration of

---

[1] Color and its Applications, D. Van Nostrand Co.

color in a discussion of the subject of light and shade, so that the more important factors have been considered briefly in a single chapter.

The treatises on light and shade that have come under the author's observation are quite incomplete and inadequate, owing to the scarcity of analytical data and discussions. An attempt has been made in this book to record many facts and tc apply the data to some extent to various fields in which they are highly important Strictly this is a treatment of the *science* of light and shade, although the *art* is discussed occasionally. The object has been to record the observations on light and shade gleaned from a study of the fundamental principles of lighting and vision. That such a work will find a field of usefulness has often been indicated by many persons interested in various fields in which light and shade are very important.

A large part of this book and a portion of its companion on Color are devoted to the presentation of those principles which underlie the influences affecting the appearances of objects. Insofar as the application of these data are concerned the author's viewpoint is expressed in the following: 'He who has learned the science of light, shade, and color, who has learned how to observe and to record them, and who has learned to manipulate them to produce various effects, has learned the means by which achievements may be attained. He has grasped the science and is prepared to master the art.'

In a study of light and shade certain characteristics of objects, namely the optical laws of reflection and transmission, are of prime importance. The reasons why and how objects are seen must be learned. The effects of distribution of light, the relation of the position of, and the solid angle subtended by, the light source, and the influence of surroundings upon the distribution of light are fundamental studies. Here a distinction is made between the portion of an object receiving little or no light and the shadow cast by the object upon another object. The first has been named the shadow and the latter the cast shadow, but the two are often combined in the simple term 'shadows,' where the meaning will be readily understood.

As already stated, it is quite impossible in the presence of the gift of color vision to dissociate color completely from light and shade and, although this subject has been treated elsewhere in detail, its most important relations to light and shade have been briefly described again. The spectral character of the illuminant not only alters the hues of colored objects but has a large effect upon the relative brightnesses or values of different colors. The gradations of color upon a given object are also related to the surface character of the object, to the distribution of light, to the position of the light source, and to the solid angle subtended by it at the object.

We often go to Nature to study, and find it necessary and profitable to do so in the consideration of light and shade. Natural lighting conditions are of extreme importance, because much architecture and sculptured art are subjected to its continually varying light. A study of Nature's light supports the conclusion that nothing in Nature is constant excepting change. Nature has posed for most of the world's masterpieces in painting, and a study of its light and shade furnishes useful data for many arts. The eye, having evolved under daylight conditions, requires that natural conditions be analyzed and considered in artificial lighting, which is rapidly growing in importance in human activities.

Just as light is the master painter, so is light the master sculptor. Lighting will be shown to be of extreme importance in these respective two- and three-dimensional fine arts. Lighting is vastly influential both while the sculptor is chiseling his work and after it is completed. The sculptor sinks a hollow here and raises a ridge there, not to attain these two simple objects but to lead lines of light and shade at will in an attempt to fixate an expression of light. In reality, lighting, through the effects of lights and shadows, does the modeling. Architecture is likewise molded by lines and masses of light and shade — the results of lighting. The architect and sculptor are at the mercy of the lighting, for their lights and shades are not fixed but depend very much upon the distribution of light. Their lights and shades are ever shifting and ever changing in character, with the position and the solid angle subtended by the light source. The ratios of the brightnesses of the high-lights to those of the shadows are dependent upon the amounts of light reaching the object directly and indirectly. Often the surface characters of the objects are such that the intrinsic brightness of the light source greatly affects the brilliancy of the high-lights. The painter, however, fixes his values, but even these are not immune from alteration by the distribution of the light which illuminates the work.

Photography is largely an art of light and shade, and real art of this character is perhaps more dependent upon a proper treatment of these than upon the selection and position of the subject. The photographic process is quite limited in its ability to record the extremes of contrast encountered, although photographic plates differ considerably in their abilities to record ranges of contrast. This deficiency is especially deplored in attempting to record many of the effects of light and shade presented in this book.

As already stated, vision largely involves the perception of differences in brightness, and it must be treated because it is concerned with every fact of light and shade from the present viewpoint. Likewise, lighting goes hand in hand with light and shade. In fact lighting and vision are so intimately related to the subject of this book that they would not be treated in separate chapters were it not considered necessary to bring certain phenomena and fundamental principles together.

In stage-craft the possibilities in light and shade are unlimited, yet they have been scarcely drawn upon. There are many incongruities existing between the real and painted light and shade in stage settings. The foot-lights produce such grotesque results that it is remarkable that they have not been condemned long ago. In fact the new movement in the theatre is partially due to a revolt against such conditions. The distribution of light and shade is an inexhaustible source of moods and expressions which can be made to blend with the play and action in a helpful yet inconspicuous manner.

The treatment of such a subject as light and shade is difficult owing to its intangibility. However, many data have been gathered and therefore an attempt has been made to record these facts and to show some of their applications. Some of the facts herein recorded will appear quite obvious, because they can be witnessed at any time, but it has been the author's experience that most persons look without observing — hence this volume.

CHAPTER II

THE CHARACTERISTICS OF OBJECTS

In order to analyze light and shade effects, and to produce them, it is necessary to be familiar with the elementary optical laws and the optical characteristics of various objects. For the present purpose it is unnecessary to delve deeply into the mysteries of light production or to enter into a discussion of modern theories of light. However, it is quite essential to form definite mental pictures of the optical laws governing the travel of light. When a body is heated the electronic disturbances taking place in the atoms of the substance are supposed to set up electromagnetic disturbances which travel unhampered through free space but are more or less interrupted in their travel by material objects. This electromagnetic energy which is radiated by the hot body is similar to the energy which is the messenger passing from one station to another in wireless telegraphy. It is found that a hot solid such as the sun radiates energy of many wave-lengths, all of which do not excite the sensation of light. In fact the visual process is excited only by energy of a narrow range of wave-lengths. These will be called light-waves or light-rays.

The foregoing brief discussion accounts for the colorless or achromatic sensations of light, but not for the colored or chromatic sensations. The latter sensations are found to be associated intimately with the wave-length, or frequency, of the visible radiation;

that is, light-waves when impinging upon the retina of the eye produce sensations of different colors, depending upon the wave-length or frequency. In other words, light-waves of a certain wave-length generally arouse a sensation of a certain color. When viewing a white diffusely reflecting surface illuminated by noon sunlight, light-rays of all wave-lengths are stimulating a given portion of the retina, with a result that a sensation of *white* is produced. If the sunlight is decomposed into its various components the visible spectrum is seen. Such a condition produces the rainbow; that is, in the rainbow the effect of each wave-length is seen alone. If the eye were sensitive to all the rays emitted by the sun, the rainbow would be more extensive in width, but inasmuch as only visual effects are of interest here, the invisible rays — the ultra-violet and the infra-red — will not be discussed. There are many optical phenomena of interest, such as reflection, transmission, refraction, interference, and diffraction, but in the study of light and shade only the reflecting and transmitting characteristics of media are of great importance.

A white surface is one that reflects rays of light of all wave-lengths with equal facility. A gray object is one that reflects all the light-waves with equal facility but to a lesser degree than a white object. A perfectly black object does not reflect light-waves at all, but absorbs the incident radiant energy, transforming it into heat. There are no perfectly white or black objects to be found, but under certain conditions these are closely approximated; for example, pure zinc white and magnesium carbonate approach closely to the ideal white, while a hole in the end of a long velvet-lined box is nearly perfectly black. (See Fig. 106.)

The reflecting power or reflection coefficient of a surface is the ratio of the light reflected by the surface to that incident upon the surface. Obviously the reflection coefficient of a perfectly white surface is unity and that of a perfectly black surface is zero. The various shades of gray have reflection coefficients varying between zero and unity. The actual brightnesses of objects not only depends upon their reflection coefficients but also upon the amounts of light falling upon them. For instance, a gray diffusing surface whose reflection coefficient is 0.4 appears of the same brightness as, and in fact identical with, a 'white' diffusing surface whose reflection coefficient is 0.8, but is illuminated to only one-half the intensity. A gradated shadow is more often produced by varying amounts of incident light than by a gradated reflection coefficient. For example, the brightness of a shadow on a sphere of uniform reflection coefficient varies because of the different amounts of light received by the different parts of the surface. This is due to the fact that various portions of the surface are oriented differently with respect to the light source. If a white surface be placed perpendicular to a line joining it and the light source, the surface will be brighter than if turned at any other angle with this line (Fig. 117). Its brightness will vary directly with the sine of this angle or with the cosine of the angle of incidence, the latter being the angle between the direction of the light and a perpendicular to the surface.

The reflection coefficients of white, black, and gray surfaces are constant for light-waves of all wave-lengths, which distinguishes neutral objects from those which appear colored. Colored pigments appear colored owing to their selective absorption and reflection.

For instance, a green pigment is one whose reflection coefficient differs for rays of various wave-lengths, it being high for green rays, lower for the other rays, and practically zero for red and violet rays. This is treated further in Chapter VI. It is well to note that light rays themselves are invisible, but they have the ability to illuminate material objects and to make the latter visible. For instance, the visible sky consists of innumerable illuminated minute particles. If there were no particles in the earth's atmosphere capable of reflecting light, the sky would appear as black during the day as at night, notwithstanding the light-rays passing through it.

The simplest optical law of importance is that the angle of reflection is equal to the angle of incidence for surfaces reflecting light regularly or specularly. This law is represented diagrammatically in *a*, Fig. 1, *I*, the angle of incidence being equal to *R*, the angle of reflection. Such reflection is named regular or specular and is often associated with the high-lights of objects. Mirrors, plate glass, and other polished and glazed surfaces reflect light in this manner. In these cases the surfaces are not visible, but the images

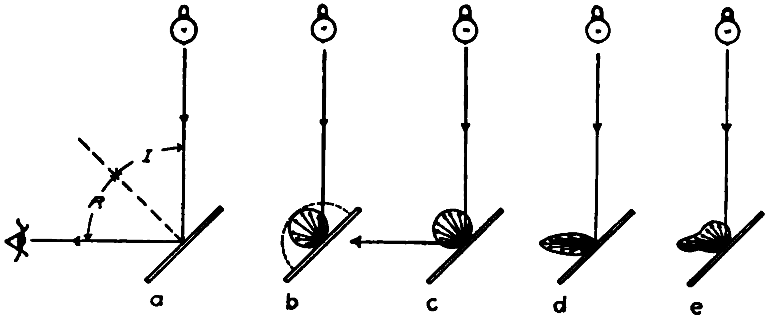


Fig. 1 — Characteristics of reflecting media.

of various objects are seen depending upon the positions of the eye, mirror, and objects. In the case shown in *a,* Fig. 1, the eye sees the image of the lamp, the latter appearing to be at a distance to the right of the mirror equal to its actual distance above. The highlights on glazed objects are at those surfaces which are properly oriented with respect to the eye and to the light source, so as to reflect an image of the latter directly into the eye; that is, the positions of the highlights shift with the point of view. The brightness of the reflected image is equal to the brightness of the object multiplied by the reflection coefficient of the polished or glazed surface. For silvered mirrors the latter ranges from 0.7 upward and for a surface of polished glass or still water it is about 0.04.

The next type of reflection of interest is that from a perfectly diffusing surface. Such surfaces are closely represented by white blotting paper, ground porcelain, and unglazed plaster. Diffuse reflection from a perfectly diffusing surface is represented in *b,* Fig. 1, the brightness being constant for all viewing angles and therefore represented by the dashed semicircle. The brightness, however, varies as the angular position of the surface is altered with respect to the line joining the element of surface and the light source. The distribution of the light reflected from any small area of a perfectly diffusing surface is represented by a sphere tangent at the small area. In a plane diagram the light flux emitted by the small area is found to vary directly with the cosine of the angle of incidence, and the distribution of light is therefore represented by a tangent circle. This is sometimes known as the 'cosine law' but owing to the fact that Lambert discovered these relations his name is usually applied to the law.

Diffusing surfaces that are glazed with a superficial coat exhibit both types of reflection as shown in *c*, Fig. 1. Examples of surfaces having such reflecting characteristics are painted walls and enameled porcelain. An excellent model can be constructed readily by placing a sheet of glass over a white blotting paper. A series of models exhibiting different proportions of specular and diffuse reflection can be made by placing blotting papers of various shades of gray beneath a thin pane of clear glass.

It is not surprising to find a great number of types of reflection that are intermediate between the types already described. The type of 'spread' reflection shown in *d*, Fig. 1, is common. An aluminized surface is an excellent example of this type. If such a surface be turned gradually while the eye and light source remain stationary, it will be found that its brightness diminishes rapidly on both sides of the critical angle of specular reflection, although at no angle will the surface reflect a defined image of the light source. When examined by means of a microscope, surfaces of this character are found to consist of minute mirrors oriented at random.

Many white surfaces, such as semiglossy white papers, reflect light as indicated in *e*, Fig. 1.

Inasmuch as the relative brightnesses of objects are of importance in all studies and applications of the science and art of light and shade, the reflection coefficients of a large number of ordinary objects are given in Table I. The surfaces cannot be accurately described, so that average values are given from data obtained by Sumpner, Nutting, the author, and others. Reflection coefficients are also presented in Tables III, IV, and VI. The reflection coefficient of a colored surface varies with different illuminants, as shown in Chapter VI. The values given here are for ordinary daylight entering a window.

TABLE I

Reflection Coefficients of Objects

Object	Reflection coefficient	Object	Reflection coefficient
White blotting paper	0.70–0.85	Sulphur	0.80
Zinc oxide	.85– .90	Cork	.25
Tracing cloth	.30– .40	Chocolate	.05
Tracing paper	.20– .30	Navy blue cloth	.02
Newspaper	.50– .70	Paris green	.40
White writing paper	.70– .75	Manila paper	.50
Yellow copy paper	.65– .70	White plaster	.70–0.90
Yellow wall paper	.40	Copper (dull)	.25
Green wall paper	.30	Brass (dull)	.25– .35
Blue wall paper (light)	.25	Gold (dull)	.20
Brown wall paper (medium)	.25	Butter	.65
Dark brown wall paper	.13	Vermilion	.15
Chocolate wall paper	.04	Emerald green	.20
Parchment	.22	Ultramarine blue	.05
Parchment (two thicknesses)	.35	Orange	.60
Tissue paper	.40	Chrome yellow	.75
Tissue paper (two thicknesses)	.55	Cobalt blue	.15
Black cloth	.02	Silvered mirror	.70– .90
Black velvet	.004	Polished glass surface	.04

The types of transmission[1] of light by various transparent and translucent media are quite similar to the types of reflection. These are represented diagrammatically in Fig. 2. The phenomenon of refraction enters into the transmission of light through material media, but is of very minor importance here. In *a′* is represented the transmission of transparent media such as clear plate glass. In *b′* is represented the type of transmission exhibited by a diffusing me-

---

[1] M. Luckiesh, Electrical World, Nov. 16, 1912; April 26, 1913.

dium such as porcelain or dense opal glass. In the case of a perfectly diffusing and non-absorbing medium 50 per cent of the incident light is diffused through the glass and the remaining 50 per cent is diffused backward. This assumes no loss of light by absorption, which ideal has never been found. A perfectly diffusing medium, illuminated as shown in *b′*, appears of the same brightness at all viewing angles. A flashed-opal glass is an excellent example of this type and has a comparatively high transmission coefficient. In *c′* is represented a common type of transmission which is exhibited by some light-density opal glasses and milky solutions. A light source can be seen faintly through such media, yet a large percentage of the light is diffusely scattered. In *d′* is found a very common type of transmission represented by ground or sand-blasted clear glasses. In *e′* is represented a type which is not uncommon. A slightly sand-blasted or roughened light-density opal glass exhibits this type of transmission. Many actual curves showing the types of transmission of various commercial glasses could be

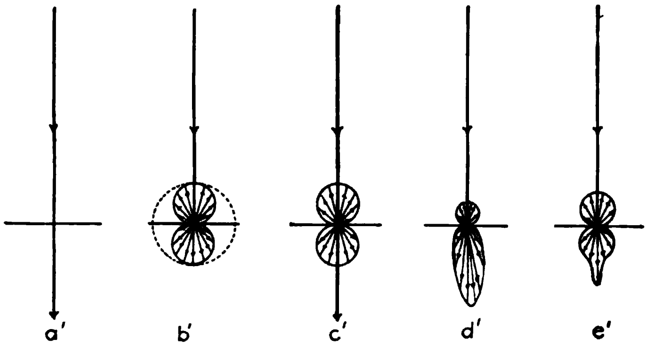


Fig. 2 — Characteristics of transmitting media.

presented, but these could only serve to corroborate the data already given.

The high-lights on objects are the reflected images of the brightest objects or sources of light illuminating them. An object can never be so bright as the light source which illuminates it, owing to absorption of light by all reflecting surfaces. If the high-lights be examined closely, they usually will be found to be the images of bright sources of light reflected from smooth surfaces of the object, and these smooth surfaces are so oriented with respect to the light source and the eye that the angles which they make with lines from them to the light source and the eye are equal in each case. (See illustrations in Chapter III.) Often it is possible to determine the character of the light source or of the lighting system from the appearance of objects, but this is not always true. For instance, a cube whose surfaces are glazed can be so placed that no reflected images of the light sources are visible from a certain position. In this instance another cube whose surfaces are diffusely reflecting and of the same color would appear quite the same as the first cube. However, in some positions the appearances of these two objects are quite different, owing to the characteristics of their surfaces.

A plane surface does not magnify or diminish the size of the image. However, convex surfaces diminish the size of the image, depending upon the radius of curvature. The image is small when reflected from surfaces of small radius of curvature, and in the case of small polished spheres the image of a window is almost a point. Cylindrical polished surfaces reflect the images of bright objects in the form of a line parallel to the axis; that is, the high-lights on such surfaces are linear. Concave surfaces are capable of magnifying and of diminishing the size of the image, but usually the high-lights are seen as images smaller than the objects themselves.

High-lights are not always visible on polished objects having plane surfaces, but they are nearly always visible on glazed or polished curved surfaces, because in the latter case nearly always there is an element of the surface properly oriented to reflect a bright image into the eye. That high-lights are dependent upon the law of equal angles of reflection and incidence can be readily investigated by means of a polished sphere. As the eye is moved with respect to the object and light source, the high-light is seen to move in such a manner that the law is fulfilled. If the brightest objects in the room are two light sources, two high-lights will be seen, their proximity to each other depending upon the distance the two light sources are apart and their relative positions. A four-light fixture will produce a group of four high-lights. A large bright area, such as a window backed by a bright sky, will produce relatively large high-lights, and if the curved surface is well polished a distinct miniature image of the window will be seen. It is noteworthy that the brightest areas on smooth objects are not nearest the light source, as is sometimes assumed. This is only true when the observer's eye is in line with the object and light source. In Figs. 3 and 4 a group of electric incandescent lamps have been photographed when illuminated by means of a large window and a point source respectively. The point source was placed in the center of the large window after drawing an opaque curtain so that the mean positions of the two light sources were respectively the same in the two cases. This group of lamps supplies a variety of surfaces which serve well in illustrating high-lights. One of the high-lights in Fig. 3 is seen to be an image of the window, while the corresponding one in Fig. 4 is a point. The lamp on the left is bowl-frosted and it is seen that this roughened surface effectively destroys the high-light in Fig. 3. It will be noted that the cylindrical surfaces produce linear high-lights which are

Fig. 3 — High-lights due to a large light source — a window.

Fig. 4 — High-lights due to a small light source — a bare incandescent lamp.

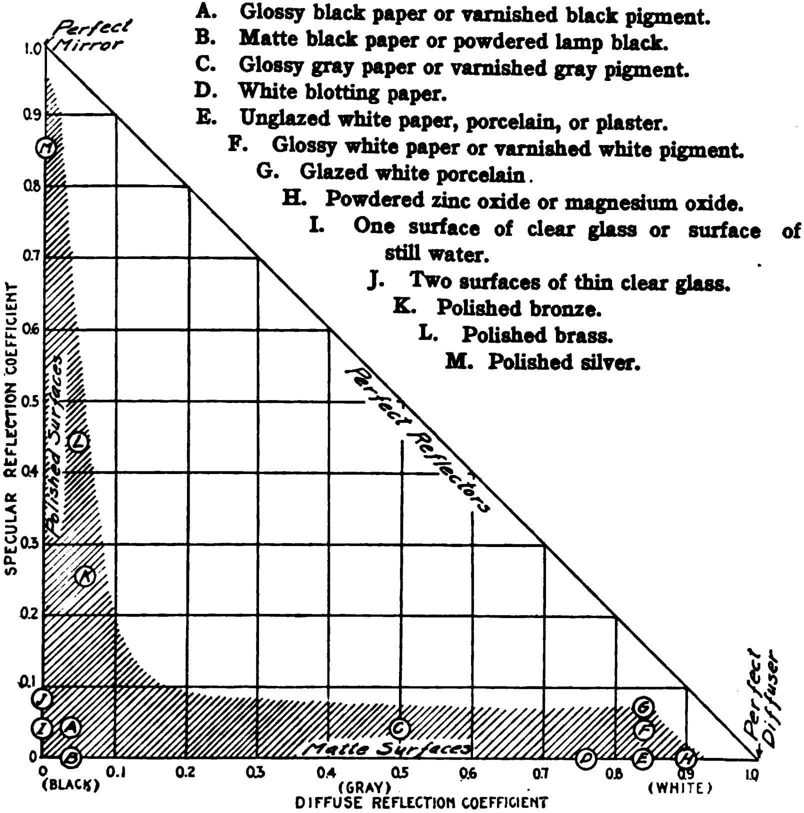
wider in the case of the light source subtending a large solid angle. The middle lamp has a white opal bulb and the lamp on the left a dense ruby bulb (black for the photographic plate used). The high-lights on these two objects are nearly of equal brightness, although that on the dark bulb appears brighter, due to contrast. In fact the brightness of the high-light on the opal bulb is greater than that on the black bulb, because the brightness due to the diffusion of light in the opal glass is added to that of the high-light. The brass base on the middle lamp is not polished, but has reflecting characteristics similar to *d,* Fig. 1; therefore the high-light on this surface is spread somewhat and is not a distinct image of the light source, as in the case of the glazed surfaces. Other interesting facts are to be noted, and the solid angular extent of the light source is seen by the cast shadows. Other data concerning high-lights are to be seen in various illustrations throughout the text. In the case of objects having a metallic finish, such as the moldings shown in Fig. 94, the detail is almost entirely revealed by bright high-lights and shadows. In Figs. 9, 10, 12, and 13, high-lights are visible on the curved surfaces, with the exception of the hemisphere on the left, which had an unglazed surface. The lighting of these objects is described in connection with other data for which these illustrations are chiefly shown. The effects of the character of the surface of objects are of special interest with respect to some of the sculptured objects illustrated in Chapter VIII.

As has already been seen many surfaces reflect light both specularly and diffusely and some are either purely specularly or diffusely reflecting. A simple diagram is presented in Table II to assist in visualizing

TABLE II

A general diagrammatic table illustrating the reflection coefficients, both diffuse and specular, of all possible substances exhibiting these distinct types of reflection singly or combined. The approximate positions of the following common substances are shown on the diagram according to their reflecting characteristics. Ordinary surfaces lie in the shaded region.

A. Glossy black paper or varnished black pigment.
B. Matte black paper or powdered lamp black.
C. Glossy gray paper or varnished gray pigment.
D. White blotting paper.
E. Unglazed white paper, porcelain, or plaster.
F. Glossy white paper or varnished white pigment.
G. Glazed white porcelain.
H. Powdered zinc oxide or magnesium oxide.
I. One surface of clear glass or surface of still water.
J. Two surfaces of thin clear glass.
K. Polished bronze.
L. Polished brass.
M. Polished silver.



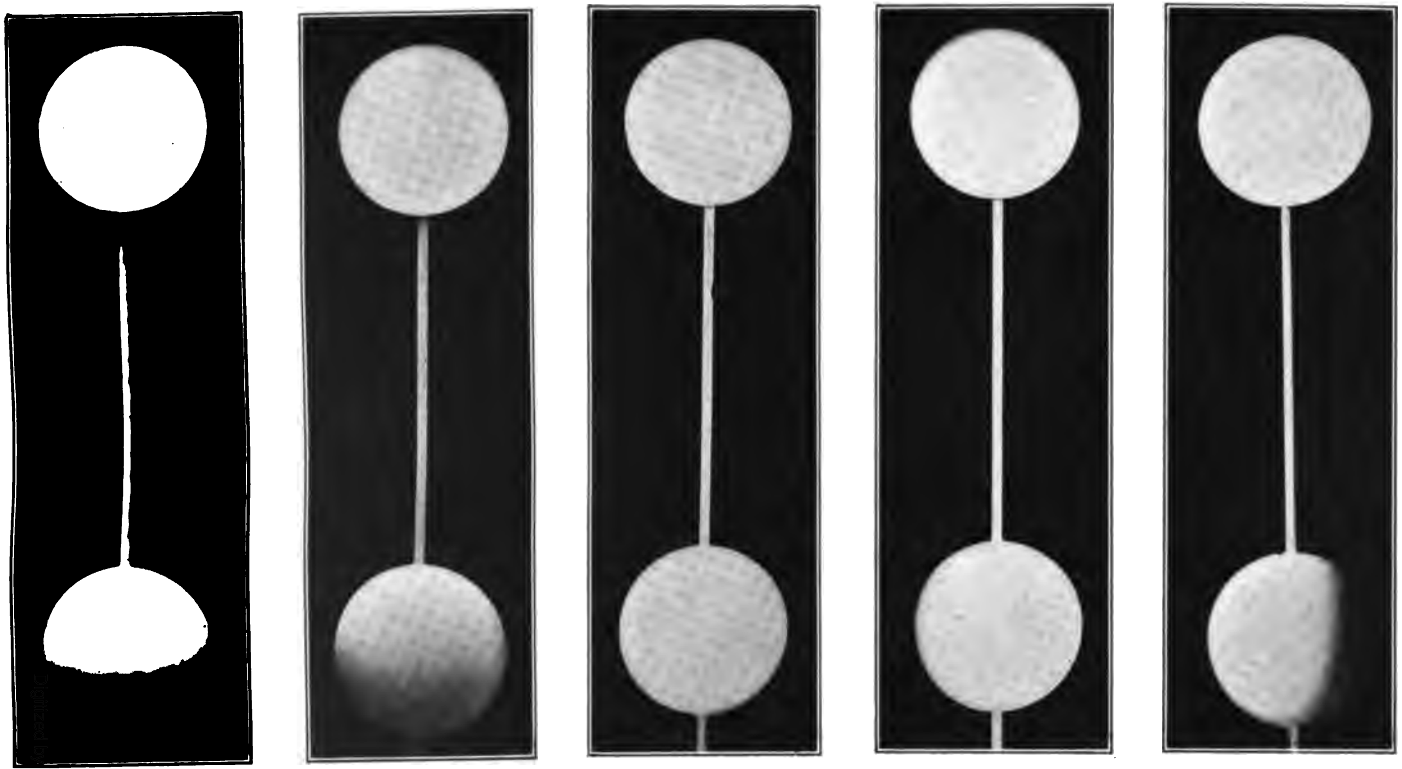
the appearances of all surfaces that reflect light in the foregoing manner according to their reflecting characteristics. There is no simple means of including objects whose reflecting characteristics are similar to *d* and *e* in Fig. 1, but the diagram in Table II provides a position for all possible surfaces having reflecting characteristics, as shown in *a, b,* and *c,* in Fig. 1. In the diagram the horizontal scale represents all possible diffuse reflection coefficients and the vertical scale all possible specular reflection coefficients. The position of a perfectly diffusely reflecting surface is found at the point on the extreme right; that is, at the point where the diffuse reflection coefficient is unity and the specular reflection coefficient is zero. Along the base line perfectly matte surfaces are plotted, varying from black at the left through the various grays and to white at the right. Along the vertical axis on the left polished surfaces are plotted representing such surfaces as a polished glass near the bottom, a silver mirror near the top, and a perfectly reflecting mirror at the top point. Such polished metallic surfaces as gold, copper, bronze, and brass would be represented in the intermediate positions near the vertical axis. Those surfaces that are so highly polished as to reflect little or no light diffusely are found respectively near or upon the vertical axis. Perfect reflectors, whether they reflect all the incident light specularly or diffusely or by a combination of the two manners, would be plotted at a proper place along the hypothenuse of the triangle as indicated. Obviously there are no surfaces having reflection coefficients as high as unity or 100 per cent. Any point within the triangle represents a surface that reflects light both specularly and diffusely; however, most of the ordinary surfaces will lie in the shaded area. It is well to note that the reflection coefficient of a matte surface is constant regardless of the angular position of the surface with respect to the light source. This is not true of the specular reflection coefficient, for it increases with the angle of incidence of the light reaching it. Obviously, for the purpose of comparison, the specular reflection coefficient must be obtained at the same angle of incidence of the light for all surfaces. This angle can be any desired, although an angle of incidence between 45 degrees and zero, and preferably near the latter, should be chosen. The center of the circles designated by letters on the diagram represents in each case the approximate position of various ordinary surfaces as determined by their two distinct reflection coefficients. Perfectly matte or perfectly polished surfaces do not exist, but in some cases these are closely approached. In Table II the various ordinary surfaces corresponding to the designating letters in the circles are given. A study of this diagram will be helpful in becoming acquainted with the appearances of objects as determined by their specular and diffuse reflecting characteristics.

CHAPTER III

THE SHADOW

It has been found necessary for the purpose of analysis to differentiate between the shadow and the cast shadow. The shadow is assumed to be that portion of the surface of an object which receives distinctly less light than the other portions. The cast shadow is assumed to be the shadow cast by one object upon another by intercepting the direct light which would otherwise reach the latter object. The forms of objects are usually determined by the distribution of light and shade upon them, although this is not always true, as will be shown later. Often the cast shadow and the known position of the light source assist the observer in determining the form of an object. However, the exact process by which an observer arrives at his conclusion is seldom analyzed by him. Although light and shade cannot always definitely reveal the form of an object, it is of very great importance in vision, playing a leading role in nearly every visual impression. It was light and shade that first made painting more than mere drawing, and all the early art shows by the absence of light and shade that the eye without knowledge cannot discover truth. It is the object of this chapter to bring forward the important facts concerning the shadows on objects as affected by the character of the objects and of the distribution of the light illuminating them.

That light and shade play an important part in modeling an object or in revealing its form is shown in Fig. 5.



(a) Direct lighting.

(b) Indirect lighting.

(c) Diffused light.

(d) Window in front.

(e) Window on side.

Fig. 5 — Appearances of a disk (above) and a sphere (below) under five different lightings.

A white diffusely reflecting disk was placed on a rod on which also was placed a white diffusely reflecting sphere. These were suspended vertically and photographed under various lightings. In *a* are shown the effects of a point source of light placed nearly vertically above. It is seen from the dense shadow on the lower side of the sphere that relatively little diffused light reaches the objects. It will be noted that in all cases the disk appears flat and would be readily distinguished as a flat surface. However, as will be seen, the observer must consider other factors (perhaps unconsciously) before he can be absolutely certain that the disk is a flat surface. As will be brought out later, judgments are perhaps always influenced by past experiences, and in this case the disk would be pronounced a disk because the observer seldom or perhaps never has seen a special case where another object was so lighted as to appear like a disk. Such a lighting, however, can be easily performed with a sphere or hemisphere. Of course even in this case the disk might very well be the flat surface of a hemisphere, but what lies behind and invisible does not concern us here. It should be noted, however, that the eye is usually more sensitive to variations of brightness than the photographic plate, so that it is capable of distinguishing differences in brightness that are not revealed by the combined photographic processes necessary to produce the illustrations in this book.

The appearance of the disk and sphere when placed a few feet directly beneath an ordinary indirect light-unit is shown in *b*, Fig. 5. In this case the ceiling of the room is the chief source of light and the effect of this large source is shown by a less abrupt modulation on the sphere from light to shadow than in the case of the small source, the effects of which are shown in *a*. Further, the illuminated shadow on the sphere in *b* shows the effect of scattered or diffused light resulting from this kind of lighting. Although the amount of light finding its way into the shadows is usually less for such a case as *a*, in either case the amount of light received by the shadows in ordinary interior lighting conditions is usually as low as five to fifteen per cent. Of course this depends upon many factors, the chief ones being the proximity of the object to the primary light source and the reflection coefficients of surrounding walls.

Next the objects were lighted by an ordinary direct lighting unit and the direct light was screened from them. They now receive only the diffused light that ordinarily illuminates the shadows, which is usually, in the case of rooms having fairly uniformly bright surroundings, about of equal value in all directions in the center of the room. The result is shown in *c*, and it is seen that the disk and sphere appear alike. In this case it was impossible to distinguish between the two from the appearance of their surfaces.

Next a large window through which only sky was visible was used as the light source. The camera was placed between the objects and the window and, as will be seen in *d*, the two objects appeared almost identical. The camera was not quite in line with the objects and the window, as will be seen by the suggestion of a shadow upon the left side of the sphere. Leaving the objects in the foregoing position with respect to the window, the camera was moved to a position at the side of the objects with the result as shown in *e*. Here it is seen that the point of view of the observer is of considerable importance in facilitating the recognition of objects.

Although the distribution of brightness over the surface of an object usually reveals the identity of the object, as already stated, this is not always true. This is illustrated in Fig. 6. The two objects appear to be hemispheres lighted from the lower right and upper left sides respectively. However, the object on the left was a plaster mold made with the hemisphere on the right as a pattern, and both objects were photographed at the same time while lighted from a window on the left side. Thus it is seen that the hollow or recessed hemisphere on the left, into which the solid hemisphere on the right fits perfectly, appeared almost like a solid hemisphere, though the position of the light source appears to be directly opposite to the real position owing to the reversal of the light and shade. On lighting this hemispherical cup from concealed light sources in a booth lined with black velvet, every observer believed it to be a solid hemisphere and was quite surprised to find it in reality a recess. On observing this object when the light source was not concealed, observers usually described it correctly, but did so by semiconsciously taking into account the position of the light source in connection with the position

Fig. 6 — A hemispherical recess (left) and a hemispherical solid (right) lighted by a window on the left.

of the shadow. This is one of the many examples which illustrate the complexity of the process of recognition of objects. Here light and shade alone failed to reveal the true form of the object, because solid hemispheres are more common than reversed hollow ones, as that on the left; however, the position of the light source aided the observer in forming true judgment. In Fig. 7 are shown the results obtained by lighting those two objects by means of a point source. When they are viewed simultaneously under this lighting quite a difference is noted in the edge of the shadow. That on the object at the left is cast by the sharp edge of the hemispherical cup and therefore is sharp. The shadow on the right-hand object is gradually formed by the varied positions of the elements of the spherical surface. These points are brought out in Figs. 70 to 73 inclusive by means of a relief and the mold in which it was cast.

Fig. 7 — A hemispherical recess (left) and a hemispherical solid (right) lighted by a point source on the left.

In order to provide illustrations for emphasizing various points throughout the following chapters and to provide further data on the influence upon the shadows of the position and character of the light sources, a group of geometrical objects was studied and photographed under various conditions. The cast shadows were eliminated from consideration by using a background of black velvet and the objects were placed in two rows upon a rack, which was also covered with black velvet. All the objects were enameled white with the exception of the hemisphere at the left, which was coated with an unglazed diffusing material. The enameled objects reflected light both diffusely and specularly, as shown in *c*, Fig. 1. In Fig. 8 the results obtained with a point source of light three feet overhead are shown. The high-lights on the glazed objects having curved surfaces were visible on the negative, but were sacrificed in the printing in order to preserve some light in the shadows of the perpendicular surfaces. The high-lights are visible in several of the illustrations that follow. It is seen that the position of the light source could not be determined from the appearances of the cone and pyramid, but is readily determined from the appearance of the other objects. The rather abrupt modulation from light to shadow on the objects in the lower row reveals the fact that the

Fig. 8 — A point source above.

light source did not subtend a large angle. The effect of reflected light from near-by objects is seen in the case of the hexagonal and cylindrical objects in the upper row.

The appearances of the objects due to lighting from a point source in front just over the camera is shown in Fig. 9. The high-lights are plainly visible here and the difference in the appearance of the two hemispheres (one glazed, the other unglazed) is evident. One gains quite a different impression of these two objects, owing to the absence of a high-light in the one case and its presence in the other. The absence of high-lights from the objects having plane sides is also seen. Further, it will be noted that the appearances of the pyramid in the Figs. 8 and 9 are identical. The cones differ in appearance only by the positions of the high-light, which unfortunately are difficult to reproduce here.

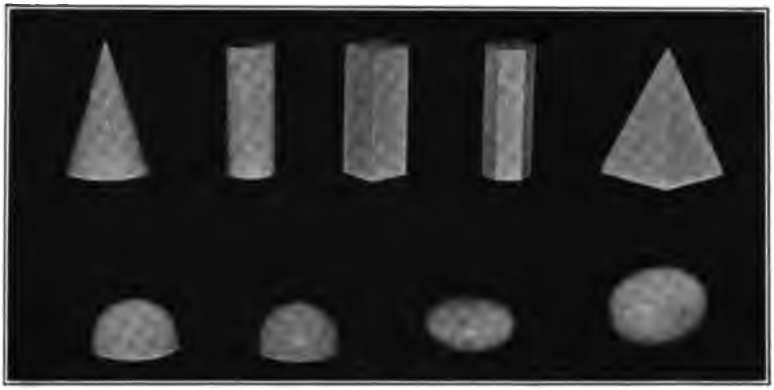


Fig. 9 — A point source in front.

In Fig. 10 are shown the results of lighting by means of a window on the left side. Definite modeling is obtained by such lighting, especially when the shadows are illuminated slightly by diffused light, as in this case. It will be noted that all the curved surfaces show a more gradual modulation from light to shadow than in the case of the point source of light.

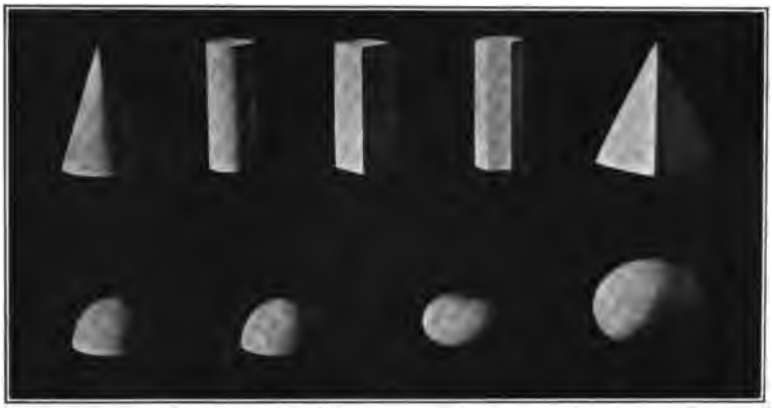


Fig. 10 — A window at the left side. Center forty-five degrees above the plane upon which the objects rested.

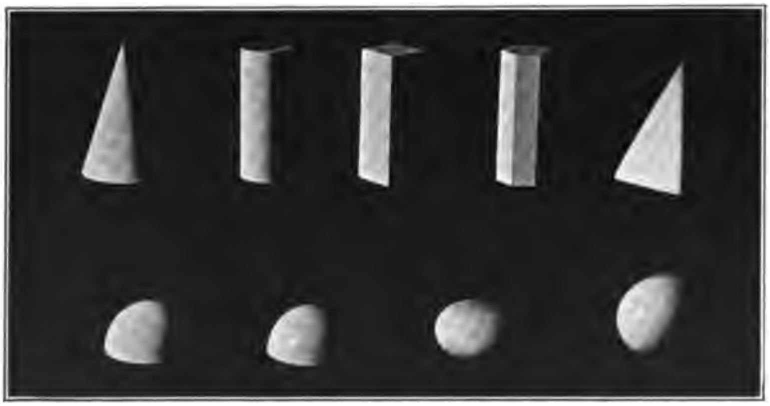


Fig. 11 — A point source in the center of the window and forty-five degrees above the plane.

In Fig. 11 are shown the results obtained by lighting the objects by means of a point source placed at an altitude of 45 degrees in the center of the window after drawing an opaque shade. The light and shade effects are almost the same as in Fig. 10, with the important exception of the abrupt change from light to shadow on the curved surfaces. The high-lights are seen to be in the same positions as in Fig. 10, but in order to preserve these, the shadows were sacrificed in the printing, there being relatively little light in the shadows in this case. Next the objects were illuminated by means of a point source at an altitude of 15 degrees and nearer the front, with the results shown in Fig. 12. In the printing, the high-lights were sacrificed in order to retain the shadows. The same general appearance of the upper rows in Fig. 11 and 12 will be noted, but the edges of the shadows on the cone, cylinder, and objects in the lower row have shifted. The simultaneous effects of the last two lightings are shown in Fig. 13, where two high-lights are seen on three of the objects in the lower row. It will be noted that the appearance of the objects in the upper row is quite the same as in Figs. 10 and 12

Fig. 12 — A point source at the left fifteen degrees above the plane upon which the objects rested.

with the exception of the two shadow-edges on the curved surfaces. These two shadow-edges are also quite marked in the lower row of Fig. 13. It is thus

Fig. 13 — The combined results of the lightings in Figs. 11 and 12.

seen among other things that the appearances of the objects having curved surfaces are more susceptible to the influence of the solid angle subtended by the light source and to the number and position of the light sources illuminating them. It is also evident that the shadow plays a large part in revealing the form of objects, but that this alone will not always suffice. In the chapters following other facts concerning shadows are presented.

CHAPTER IV

THE CAST SHADOW

The appearance of the cast shadow is susceptible to the same influences that affect the appearance of the shadow. The edge of the cast shadow, as in the case of the shadow, is affected by the solid angular extent of the light source and by the shape and distance of the shadow-producing edge. The position of the cast shadow is determined by the position of the light source. The brightness of the cast shadow depends upon the amount of scattered or diffused light reaching it. The foregoing are practically all the factors that influence the appearance of objects insofar as light and shade are concerned. In the control of these factors lies the means for success and, as is apparent, these factors can be controlled if sufficient study is applied to them.

A study of the formation of shadows is of interest and, although a mathematical discussion supplies much information for those accustomed to thinking in terms of mathematics, it appears sufficient for the present purpose to introduce the subject of the cast shadow with a few elementary diagrams. For this purpose it is permissible to assume that light-waves travel in straight lines from their source. In Fig. 14 are shown in the full lines the shadows cast by an opaque edge of the object, *O,* upon the plane, *P.* The approximate distribution of brightness in the shadow is plotted directly below in each case above the base line, *B*. Any light which indirectly reaches the plane on which the shadow is cast is said to be diffused light and illuminates all portions of the plane including the cast shadows. The amount of this diffused light is represented by the vertical distance of the dashed line, *D*, from the plane, *B*, and is shown superposed on the shadows and plane *B* by means of the dotted lines. In *a* is shown the sharp shadow cast by a point source of light. In *b* is shown the distribution of brightness of a shadow produced by a source subtending an angle of about 30 degrees at the shadow-producing edge and in *d* that due to a light source subtending an angle about twice as large as that in *b*. If the eye were placed at any point in the more heavily shaded region it would not see the light source. This region is called the umbra. However, if the eye were placed in the lightly shaded region it would be able to see more or less of the light source, in the case of an extended source, depending upon its position. This region of partial shadow is called the penumbra. The distribution of brightness in the shadow is affected by another factor, namely the distance of the shadow-

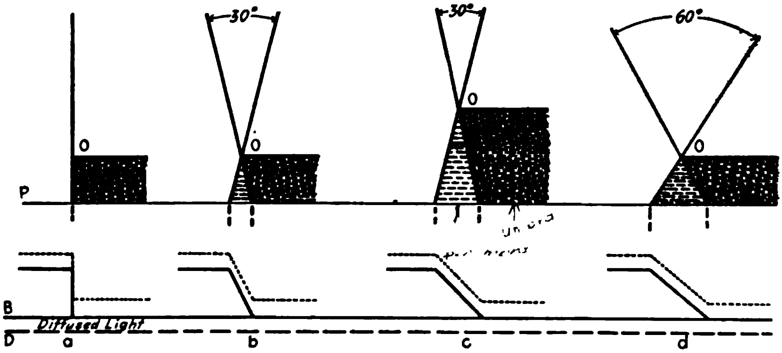


Fig. 14 — Shadows cast by a sharp edge.

producing edge above the plane upon which the shadow is cast. In *c* the opaque edge is twice the distance above the plane upon which the shadow is cast, as in *b*, though the solid angle subtended by the light sources are equal in these two cases. It is seen in *c* that the modulation from light to dark is more gradual than in case *b* and approaches the condition in *d*. In fact the rate of change of brightness in the edge of the cast shadow is approximately proportional to the ratio of the height of the light source above the shadow-producing object to the height of the latter above the plane upon which the shadow is cast. This can be demonstrated very readily by holding a flat opaque object parallel to a white surface. Under a direct light the edges of the object will appear quite alike. However, if the object be inclined so as to make an angle with the plane, the shadow of the edge nearest the plane will appear the sharpest. It is thus seen that the character of the edge of a cast shadow is similarly influenced by increasing the distance of the shadow-producing edge and by increasing the solid angular extent of the light source. For simplicity it has been assumed in the foregoing that all points of the light source are equally distant from the shadow-producing edge of the object and that the light source appears of uniform brightness when viewed from this edge.

The same general principles hold for small objects whose edges cast shadows that overlap. In *e*, Fig. 15, the object, *O*, is illuminated by a point source of light, with the result that a sharp shadow is cast upon plane *P*. The brightness distributions in the shadows are plotted above plane *B* and the diffused light is represented below this plane by the dashed line, *D*, and is shown superposed on the shadows by the dotted lines as in Fig. 14. In these cases two lines are drawn from the extremities of the light source because two shadow-producing edges are to be considered for each ray of light. In *f* and *g*, Fig. 15, the results obtained with extended sources subtending different solid angles at the shadow-producing edge are shown. In the first case the shadows of the two edges just touch each other, so that the gradation of brightness in the shadow is from a maximum to a minimum and thence to a maximum. In case *g* the shadows overlap with the results shown. The influence of the relative amount of diffused light is seen; the greater this is, the less conspicuous is the shadow. In other words the tendency of diffused light is to obliterate shadows.

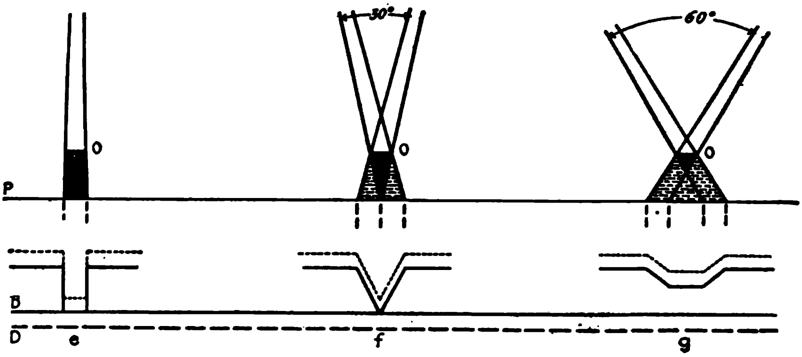


Fig. 15 — Shadows cast by a small object with two sharp edges.

The dependence of the appearance of the cast shadow upon the distance of the object from the surface upon which the shadow is cast is shown in Fig. 16. A mercury arc tube was placed 100 cm. from a photographic plate upon which the shadow of a thin edge of an opaque object was cast. The distance of this opaque object from the plate was varied from 0 to 6 cm. with the results as shown. The length of the tube of light was 75 cm. The conditions of these experiments are represented diagrammatically by *b* and *c* in Fig. 14. It is seen that even small ratios of the distance of the object from the plane receiving the cast shadow to its distance from the light source produce very soft shadows in the case of light sources

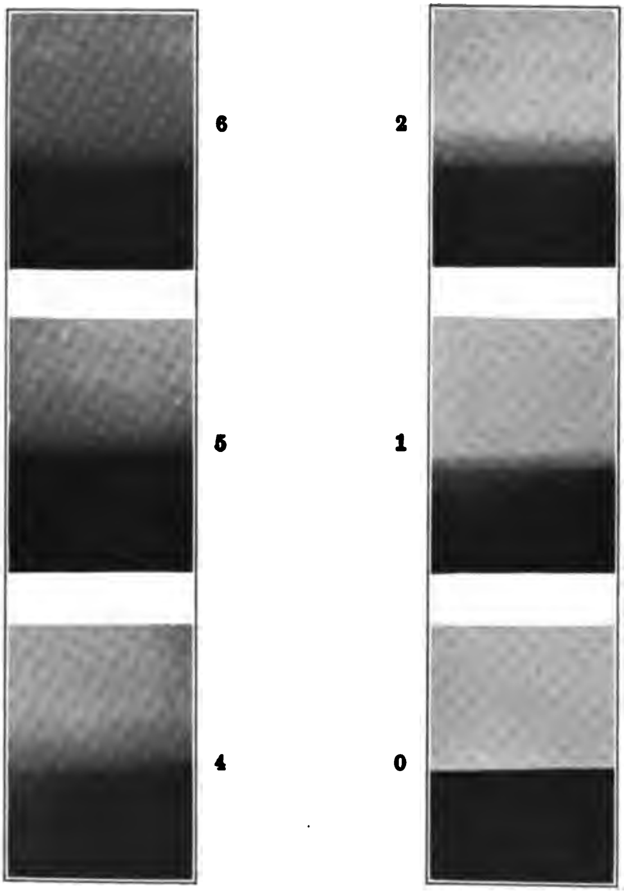


Fig. 16 — Showing the effect on the edge of the shadow of varying the distance of the shadow-producing edge, the other conditions remaining constant.

subtending large solid angles. Such facts as these are being applied constantly in the arts, such as sculpture, lighting, and portrait photography, although usually unconsciously.

The brightness of shadows can be controlled by altering the reflection coefficient of the surroundings and thus altering the amount of light received by them. The position of the shadows or their general direction can be controlled by altering the position of the light source. Where this cannot be done, as in the case of natural light out of doors, the procedure must be governed by the requirements in each particular case, with the object of obtaining satisfactory results in some other manner.

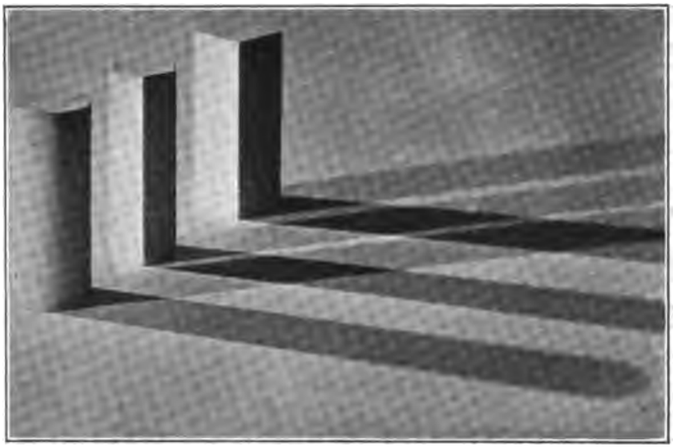


Fig. 17 — Shadows reënforce each other.

The brightness of the cast shadow under ordinary conditions is never zero; that is, though usually much darker than its surroundings, it is far from being absolutely black. This is shown by crossing two shadows, which at the same time illustrates that two shadows when crossed reinforce each other. In Fig. 17 two groups of shadows produced by two point sources of light at different positions are seen to cross each other. It is seen where they cross that the shadow is darker than either shadow alone. The actual brightness of the crossings depends of course upon the original brightnesses of the individual shadows.

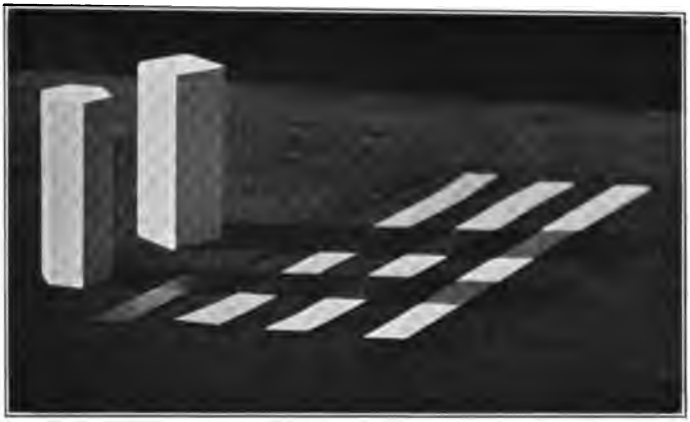


Fig. 18 — The brightness of a shadow is influenced by the reflection coefficient of the surface upon which it exists.

Another point regarding shadows which also illustrates that cast shadows are not of zero brightness, excepting in the special case of no scattered or diffused light reaching them by reflection from other objects, is illustrated in Fig. 18. The shadows cast by two objects are made to fall upon a black velvet covering and strips of black, dark gray, light gray, and white papers. It is seen that the brightness of the cast shadow depends upon the reflection coefficient of the surface upon which it is received. The nearer end of the strip of black paper is quite bright, due to the specular reflection of the image of one of the sides of the rectangular solid from its slightly calendered surface.

The shape of the cast shadow depends upon the shape of the surface upon which it is received. A group of objects was placed upon a black velvet background and illuminated by means of a large window. The center of the sky area visible at the object was at an angle of 45 degrees above the horizontal plane on which the group of objects was placed. The cast shadows under these conditions were far from sharp and were not sufficiently definite to illustrate the point under consideration, as seen in Fig. 19. The same group was illuminated by means of a point source placed at 45 degrees above the plane on which the objects were located (in the center of the window after the opaque shade was drawn) and the shadows were cast by the objects upon the various surfaces adjacent to them. It is seen in Fig. 20 that the shadow cast by straight edges upon curved surfaces were curved and upon plane surfaces were straight. The general difference in the results obtained by the light from a window and a point source respectively is also worthy of attention.

Fig. 19 — Illuminated by a window at the left with its center forty-five degrees above the horizontal plane upon which the objects rested.

Inasmuch as the character of the cast shadows produced by various ordinary light sources and lighting systems are of extreme importance in the science and art of light and shade, considerable study was given to this phase of the subject. Various methods of obtaining such data were tried, but the one which best met the requirements is illustrated diagrammatically in Fig. 21. A wooden box was attached to a camera, and this combination was placed upon a tripod. The objects selected for these experiments were a sphere, a thin cylindrical rod, a miniature table, a thick cylinder, and a rectangular solid. These were made of metal and blackened. The ob-

Fig. 20 — Illuminated by a point source at the left forty-five degrees above the plane. Illustrates the influence of the shape of the receiving surface on the appearance of the shadow.

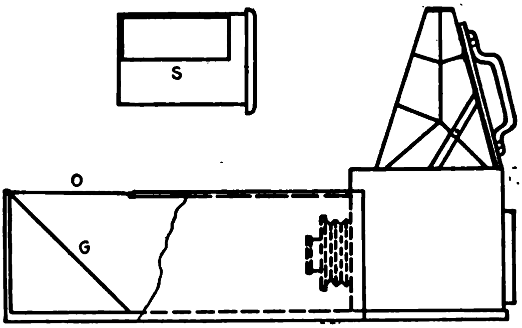


Fig. 21 — Apparatus for studying cast shadows.

jects were placed upon a flashed-opal glass, *O,* ground on the opal surface. By means of a mirror placed at *G,* the cast shadows of these objects could be seen on the focusing screen of the camera and thus photographed. An ordinary mirror was unsatisfactory, because of the double image due to reflection from both the upper glass surface and the silvered surface. Inasmuch as an ordinary photographic plate was to be used, a plane ruby glass was employed as a mirror, because the reflected light from the second surface, which was red light, did not affect the photographic plate. It was found expedient to use two identical sets of objects arranged in parallel rows on the diffusing glass, *O,* and by means of a slide, such as *S,* either set of cast shadows could be photographed. The group of objects used is shown in Fig. 22. The results obtained by this means are shown in the illustrations following.

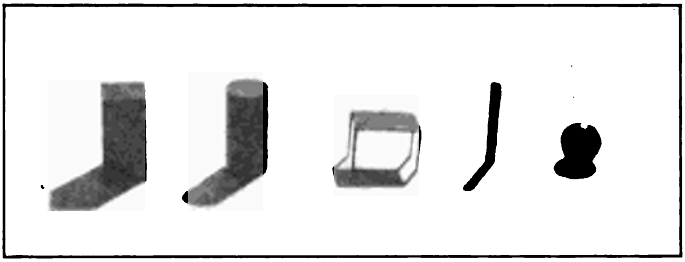


Fig. 22 — The objects used for studying the influence of the light source on their cast shadows.

Fig. 23.—The objects were placed near the sill of a window 3.5 feet wide and 6 feet high, and received light from the sun and a portion of the sky. It is seen that the cast shadows are sharply outlined.

Fig. 24.—The objects were placed three feet from the foregoing window and received light only from a

portion of the sky. The effect of a large source in producing undefined shadows is very apparent.

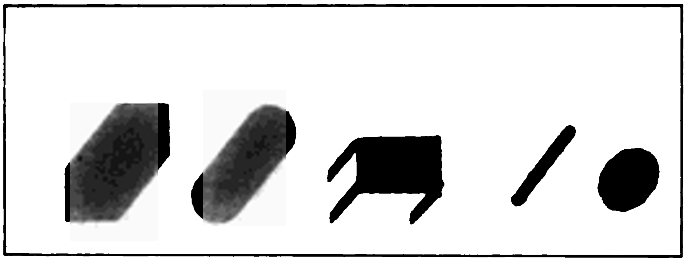


Fig. 23 — Near a window and receiving direct sunlight and skylight.

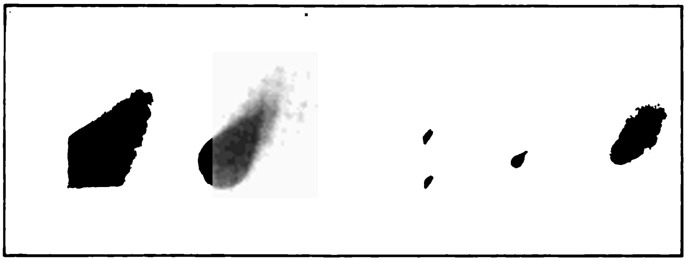


Fig. 24 — Three feet from a window and receiving only skylight.

Fig. 25 — Eighteen feet from a window and receiving only skylight.

Fig. 25. — The objects were placed eighteen feet from the foregoing window. It is seen that the window has approached a point source considerably. Only light from the sky illuminated the objects.

Fig. 26.—The objects were left in the same position as in Fig. 25, but a side window fourteen feet distant was uncovered. The objects received only light from the two sky areas. The double shadows are quite apparent. These may be useful at times, but are often annoying and in artistic effects are usually quite unsatisfactory.

Fig. 26 — Eighteen feet from one window, fourteen feet from another and receiving only skylight.

Fig. 27 — Tungsten lamp twelve feet distant.

Fig. 27.—The objects were illuminated by means of one lamp in a four-light fixture. These lamps were so far distant (12 feet) as to be virtually point sources. A slight amount of diffused light illuminated the shadows.

Fig. 28.—The objects were illuminated by means of two lamps in the foregoing fixture. The double

shadow is very apparent. This is not an unusual condition, is annoying for much fine work, and is especially unsatisfactory for the illumination of human faces, sculptured objects, and many other things.

Fig. 28 — Two tungsten lamps two feet apart and twelve feet distant.

Fig. 29.—The four lamps illuminated the objects with the resulting multiplicity of shadows as seen. This four-light fixture is a common fixture in use daily.

Fig. 30.—The light unit was of the so-called semi-indirect type, from which some of the light comes

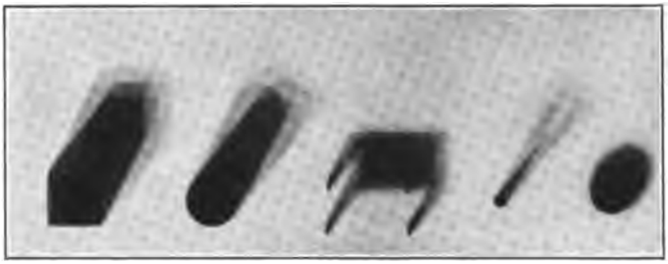


Fig. 29 — Four tungsten lamps twelve feet distant.

directly to the objects and some of it arrives indirectly by way of the ceiling, walls, etc. It is seen that the shadows, though not dark, are quite well defined. Such a unit gives practically the same results as a direct unit amid highly reflecting surroundings, although semi-indirect units differ widely in the amount of direct light which they emit in a general downward direction.

Fig. 31.—A so-called indirect unit was employed in this case. The ceiling is the chief secondary source of light, and the effect of this extended source is noted in the undefined shadows.

Fig. 30—'Semi-indirect' lighting.

Fig. 32.—Inasmuch as the new high efficiency tungsten lamps have become popular in the field of portrait photography, some experiments were made on the shadow-producing effect of a lamp devised by the author for portraiture. In this case the bare lamp was used at a distance of three feet. Although the filament is confined to a small volume, the effect in this case is not quite that due to a theoretically point source; how-

Fig. 31—'Indirect' lighting.

ever, the shadows are usually too sharp for ordinary portrait photography.

Fig. 32 — Photographic tungsten lamp (bare). Distance three feet.

Fig. 33. — The lamp in this case was placed in a white enamelled reflector. The point source still remains effective, but the effect of the white reflector, which had an aperture of 16 inches, is visible, due to the light from this extended area creeping into the shadows. The distance of the light unit from the objects was three feet.

Fig. 33 — The same lamp in a white-enamelled reflector. Distance three feet.

Fig. 34. — The light unit remained at the same position (three feet from the objects), but the aperture of the reflector was covered by means of a piece of tracing cloth. The softer effect produced by this more extended light source is evident. Practically the same

result would be obtained by means of a source 32 inches in diameter at double the distance — six feet.

Fig. 34 — The foregoing unit with tracing cloth over the aperture of the reflector. Distance three feet.

Fig. 35. — The light unit was the same as used in Fig. 34, but the distance from the objects was twice as great, namely six feet. It is seen that the effect is again approaching that of a point source. Obviously, if the size of the unit had been doubled when its distance was doubled, the effect would remain practically the same as in Fig. 34.

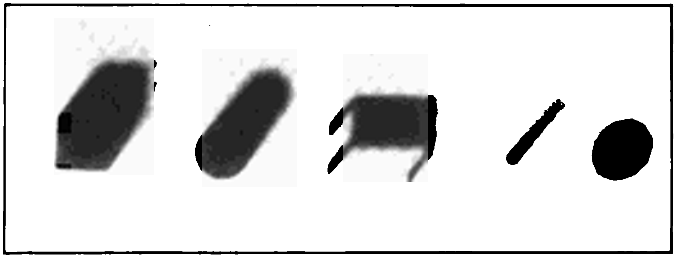


Fig. 35 — The same outfit at a distance of six feet.

Fig. 36. — The same unit was used as in Figs. 34 and 35, but the distance was changed to ten feet. The effect is now more nearly that of a point source. In order to obtain approximately the same character of cast shadows as in Fig. 34 at a distance of ten feet

the diameter of the light unit would have to be increased to about 53 inches.

Fig. 36 — The same outfit at a distance of ten feet.

Fig. 37. — The unit was a ground-glass globe ten inches in diameter containing a gas-filled tungsten lamp, and its distance from the objects was four feet. It is seen from the shadows produced that the light is emitted chiefly from a small bright spot always visible with ground-glass globes. Some effects of a superposed extended source (the luminous globe) are just visible.

Fig. 37 — A tungsten lamp in a ground glass globe ten inches in diameter. Distance four feet.

Fig. 38. — The ground-glass globe in Fig. 37 was replaced by a highly diffusing opal glass globe ten inches in diameter. The effects produced approach those in Fig. 34; that is, the source has been definitely extended,

with the result that the shadows are not as harsh as in Fig. 37. The distance was four feet, as in the preceding case.

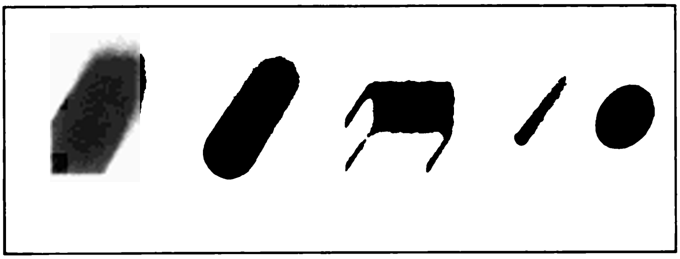


Fig. 38 — A tungsten lamp in an opal glass globe ten inches in diameter. Distance four feet.

Fig. 39.—These effects were obtained with a mercury tube, twenty inches long, placed in a vertical position at a distance of three feet from the objects.

Fig. 40.—The conditions were the same as in Fig. 39 but the tube was inclined at an angle of 45 degrees in a position so that the length of the tube was in a plane parallel to that containing the row of objects.

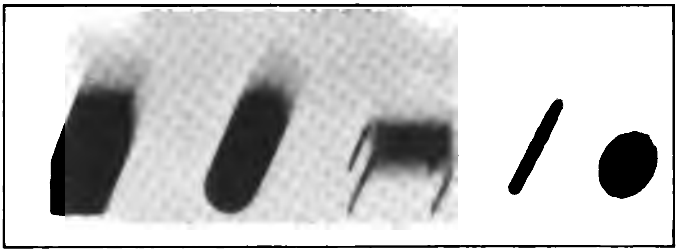


Fig. 39 — A mercury vapor arc with the tube in a vertical position.

Fig. 41.—The conditions were the same as in Fig. 39 but the mercury tube was dropped to a horizontal position.

The foregoing experiments are interesting from all standpoints of lighting, which obviously plays an important part in nearly all human activities. A thorough study of the foregoing results is recommended to the reader.

In studying the production of shadows it became evident that beautiful patterns could be obtained very simply by means of multiple shadows cast by an object lighted by means of light sources systematically placed. Various possible uses for such a simple method of producing patterns have occurred to the author, among them being attractive displays. Another possible practical application might be in the design of patterns which can be done very easily. Beautiful color effects can be produced by using colored lamps and the author has actually used the method in demonstrating color-mixture as described elsewhere.

Fig. 40 — A mercury vapor arc with the tube inclined at forty-five degrees.

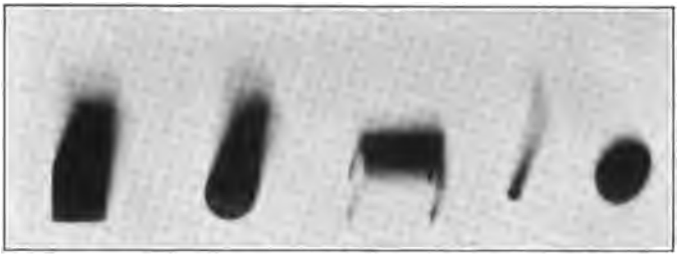


Fig. 41 — A mercury vapor arc with the tube in a horizontal position.

Some very simple effects produced by means of an ordinary four-light fixture about eight feet above the shadow-producing objects are shown in the figures following. A flat ring (an ordinary washer) was placed on a horizontal sheet of plate glass directly beneath the four-light fixture a few inches from a photographic plate. The four cast shadows intermingled symmetrically and produced the pattern shown in *a,* Fig. 42. On lowering the ring slightly the pattern changed in appearance to that shown in *b,* Fig. 42. On placing the ring still closer to the photographic plate the shadow effect was as shown in *c,* Fig. 42. Some of the shadows were so delicate that they have suffered materially in the various reproductions necessary to illustrate them here.

Next an opaque octagon was fitted into the hole in the flat ring, with the result shown in *a,* Fig. 43. When this octagon was replaced by an opaque square the effect produced is that shown in *b,* Fig. 43. On turning this square through an angle of 45 degrees another pattern was produced. On replacing the square with a small flat ring, the complex pattern of overlapping shadows of the two concentric flat rings shown in *c,* Fig. 43, was produced.

In *a,* Fig. 44, various patterns are shown as produced by simple flat rings of various dimensions. These rings were placed at the same distance (three inches) from the photographic plate and six feet directly beneath a four-light fixture containing bare incandescent electric lamps symmetrically arranged. On moving the photographic plate somewhat closer to the sheet of plate glass upon which the rings were situated, the patterns shown in *b* were obtained. Thus it is seen that surprisingly different patterns can be

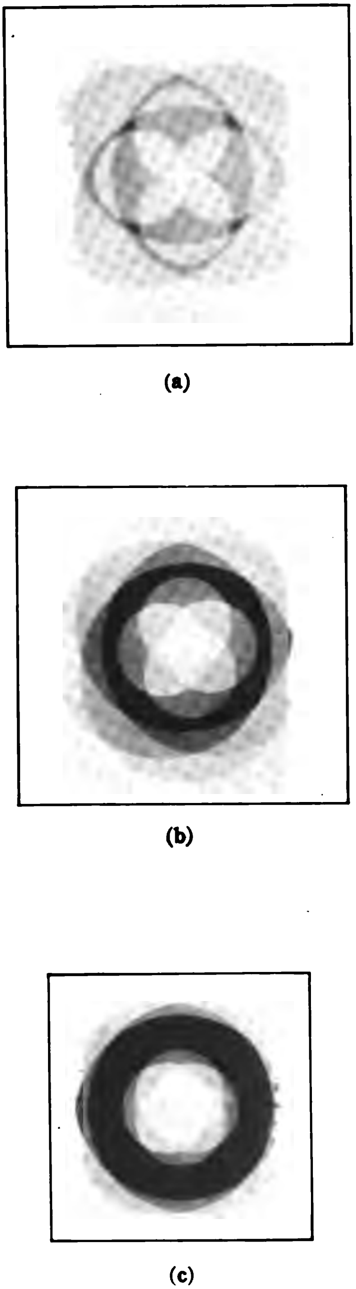


Fig. 42 — Multiple shadows cast by an annular ring. Four light sources.

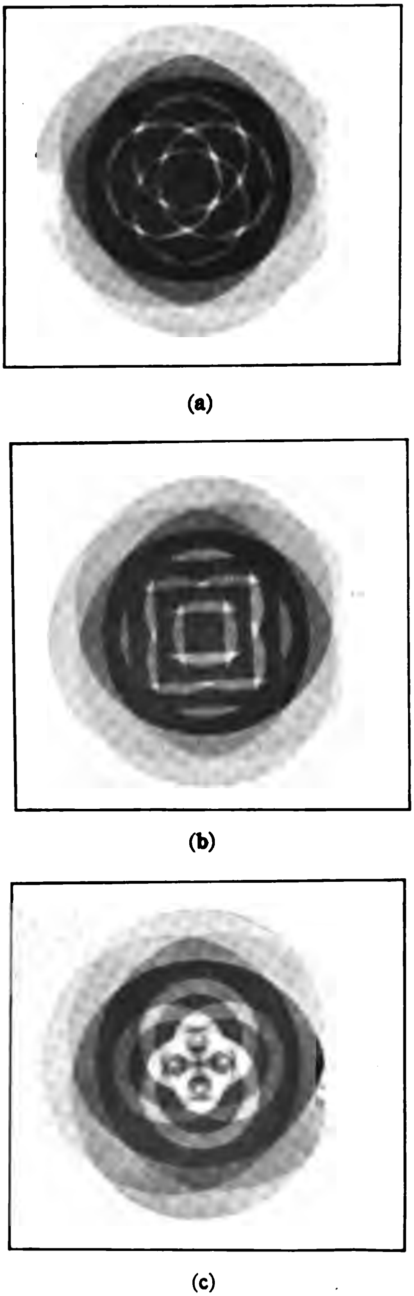
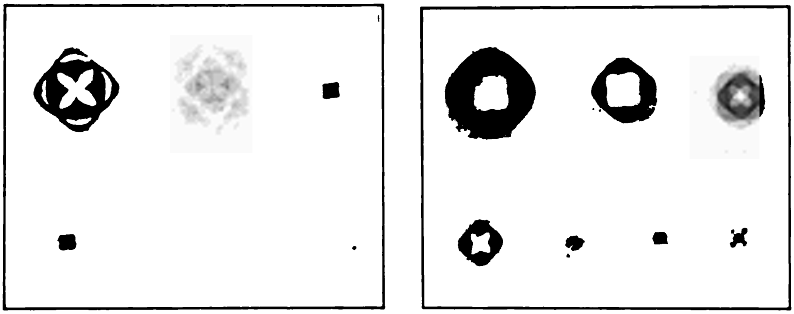


Fig. 43 — Multiple shadows of simple geometrical objects. Four light sources.

obtained by means of the same ring by varying the distance from the surface upon which the shadow-pattern is cast and by means of rings of different dimensions. In Fig. 45 are shown a few more patterns obtained by means of the multiple shadows cast by simple geometrical objects under a four-light fixture. Pattern *a* was obtained by means of an opaque octagon. On revolving this object horizontally through an angle of 45 degrees the pattern shown in *b* was obtained. In *c* is shown the pattern cast by two concentric flat rings. *d* was obtained by means of an opaque square. On turning this object through an angle of 45 degrees another symmetrical pattern was obtained. *e* was obtained by means of a 90-degree sector.



(a) (b)

Fig. 44 — Multiple shadows of annular rings of various dimensions at two different heights from the surface receiving the shadows. Four light sources.

Thus it is seen that a very large variety of patterns can be obtained by means of a few simple objects. Those shown in the foregoing illustrations were obtained by means of a symmetrical arrangement of four point sources of light. Obviously, many other patterns can be obtained by symmetrical arrangements of any other number of light sources. The asymmetrical patterns obtained by means of asymmetrical arrangement of the objects and light sources are also very interesting. The foregoing illustrations do not do justice to these surprisingly beautiful effects obtained so simply. The colored effects obtained by the use of colored lights are strikingly beautiful, due to the contrasting and mixing of the colors. The effects can be demonstrated readily by projecting the shadows upon a ground opal glass and the light sources can be arranged so that by means of separate switches any combination can be turned on.

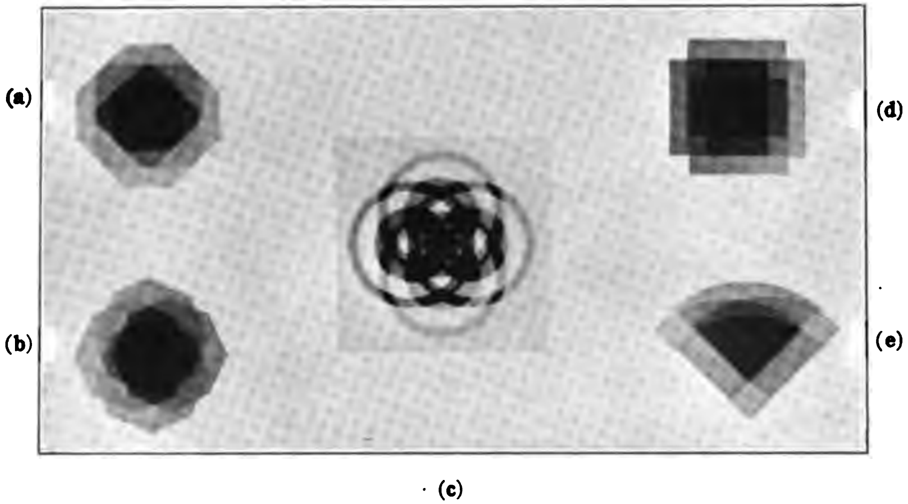


Fig. 45 — Multiple shadows of simple objects due to four light sources.

CHAPTER V

THE SCALE OF VALUES

Many of those who practise the art of light and shade are enrolled in that large class of artists which exhibits an antipathy toward the science — the foundation of their art — and therefore are prejudiced against the application of exact measurements of light. The author does not contend that art can be manufactured by means of formulæ and measuring intruments, but science and art are closely linked, because science presents the truth which art strives to represent. Science is the foundation and structure of knowledge, and in the absence of knowledge art lacks the ability to appeal. Leonardo da Vinci wrote:

> "Those who become enamored of the practise of art without having previously applied themselves to the diligent study of the scientific part of it, may be compared to mariners who put to sea in a ship without a rudder or compass and, therefore, cannot be certain of arriving at the wished-for port. Practise must always be founded on good theory."

The woful lack of scientific foundation is especially apparent in the teaching of many of the arts. The author's experience with artists in color and in light and shade indicates that the underlying sciences are quite neglected. The artist's knowledge of these sciences is usually scanty and inaccurate, and even after an extensive acquaintance with the artist, his lack of appreciation of the importance of a scientific foundation is still a source of surprise to the author. It is noteworthy and significant that the great artists in light and shade and in color have had a fair knowledge of the underlying principles — the science. By no means does the author wish to intimate that the artist should add to his kit of tools, instruments for measuring light and apparatus for mixing and analyzing colors. However, these should find a useful field in teaching pure and applied art and in developing art courses. There are many arguments for, and few, if any, against the use of instruments for learning and teaching the fundamentals of the underlying sciences and for standardizing color charts and value scales. The author has critically viewed studies in light and shade, as well as in color, made from Nature, and it has often appeared that an acquaintance with colors and values gained through the use of instruments during student days or through the use of standardized scales and charts would have developed in the artist an ability for keener perception and more accurate observation. The artist must acknowledge that the products of his tools are lights, shades, and colors which through their arrangement make an appeal to emotional man and that an accurate fundamental knowledge of these factors should be extremely helpful.

An examination of value scales in use in art courses or made by various artists shows that there is little consistency or uniformity among them. The value scale need not be made with the extreme exactitude employed in most of the physical standards, but it can be standardized to such an extent that it may be reproduced with a fair degree of accuracy and have a definite meaning. In Fig. 46 are shown the results of brightness measurements on a value scale found in a well-known book on art education. The black dots represent the relative brightnesses (scale on left side) of the various values in the value scale commonly known among artists as black, low dark, dark, high dark, medium, low light, light, high light, and white. The scale on the right side is one of actual reflection coefficients. This scale of values is the most regular and consistent scale among those examined, but owing to the difficulty of printing deep blacks, the two darkest values are brighter than they should be to represent a regularly gradated scale.

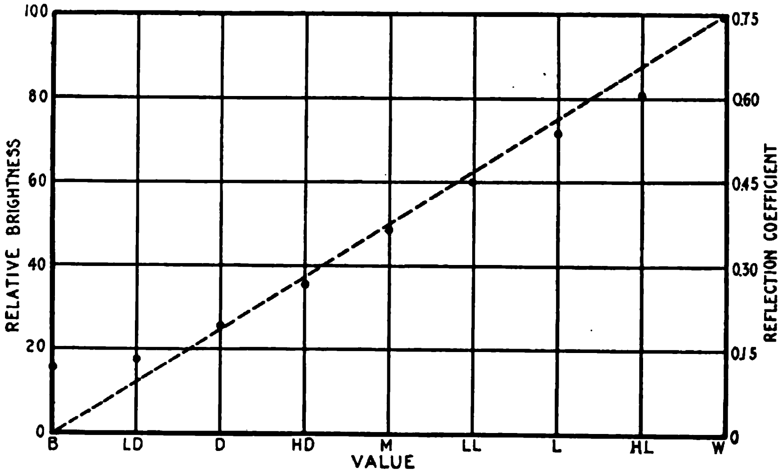


Fig. 46 — Analysis of a scale of values.

The known facts of vision pertaining to the perception of differences in brightness indicate that there should be at least the same interval of brightness between adjacent values at the darker end of the scale as between adjacent values at any other portion of the scale. Perhaps it is sufficiently accurate for practical purposes to have a value scale closely approach the dotted straight line in Fig. 46. The actual measurements of brightness obtained with this scale are presented in Table III.

TABLE III

Results Obtained from an Examination of the Most Uniform Value Scale Found

Value	Relative brightness	Reflection coefficient
B (black)	15.5	11.6
LD	17.8	13.3
D	25.8	19.3
HD	35.3	26.6
M	48.7	36.4
LL	60.3	45.2
L	71.3	53.4
HL	80.6	60.4
W (white)	100.0	75.0

The only large corrections of this scale are for HL and the two darkest values. The HL value should be 10 per cent brighter, LD somewhat darker, and the B value considerably darker — the blackest pigment available. In order to provide standard sets of reflection coefficients for the nine values in common use, Table IV is presented. The governing factors in formulating a table of reflection coefficients for the representation of the value-scale are the reflection coefficients of the available 'black' and 'white' materials and the common use of nine steps in the value scale. The blackest pigments reflect some light, the nearest approach to black being a hole in a light-proof box whose interior is lined with black velvet. When compared with this hole the blackest pigments are seen to reflect some light; that is, they are considerably brighter than the black hole. So-called black ink used in printing often reflects as much as ten per cent of the incident light, and the so-called 'whites' are found to vary considerably in reflecting power. A paper will be considered white when its reflection coefficient is as low as 0.70, and yet the reflection coefficients of so-called white materials range as high as 0.90 and sometimes slightly above. The reflection coefficients of so-called white pigments used in painting vary from 0.75 to 0.90. Of course a paper having a reflection coefficient of 0.75, although appearing white when viewed alone or in comparison with surfaces of lower reflecting power, will appear light gray when compared with pure zinc oxide, or materials having reflection coefficients as high as 0.90. It should be noted that judgments are always relative and in ordi-

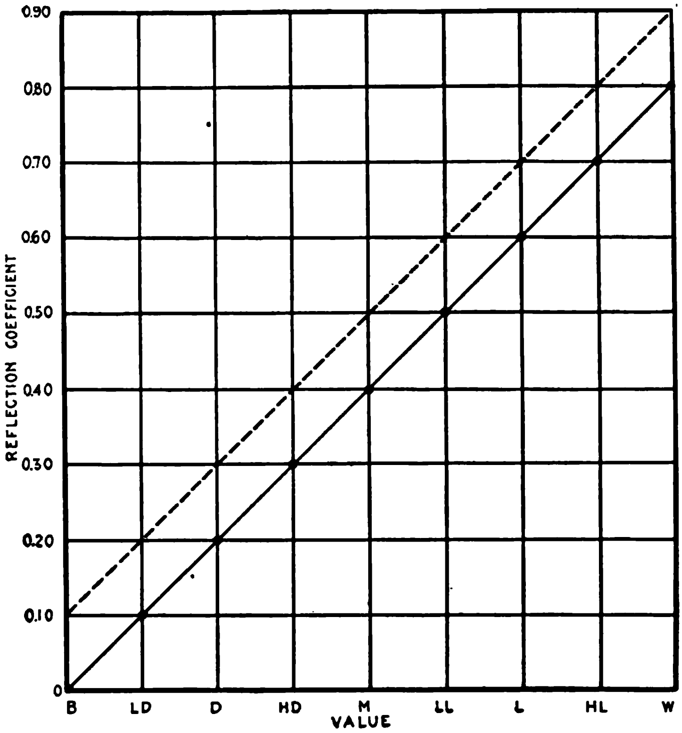


Fig. 47 — A standard scale of values.

nary vision are only estimates, so that in formulating a scale of values it appears necessary in order to establish a working basis to allow a certain range for each of the nine values commonly used. After a consideration of the limiting factors the scale as given in Table IV appears to provide a consistent and simple standard. A range is allowed in order to provide a place for all measured relative brightnesses or reflection coefficients with the lower limit in each case to be the ideal and from which the value scale shown in Fig. 47 is plotted. The lower limit for white (reflection coefficient, 0.8) represents a common value for commercial white pigments and papers.

TABLE IV

Proposed Standard Value Scale

Value	Reflection coefficient
B (black)	0.00–0.10
LD	.10– .20
D	.20– .30
HD	.30– .40
M	.40– .50
LL	.50– .60
L	.60– .70
HL	.70– .80
W (white)	.80– .90

The full line in Fig. 47 represents the proposed standard scale and the dotted line the upper limit of the range in each case which provides a place for all measured reflection coefficients or relative brightnesses. Commercial pigments and surfaces, ordinarily encountered, having reflection coefficients as high as 0.90 are rare; therefore this scale provides a place for all ordinary values. It should be noted that only relative values or brightnesses are of interest in ordinary vision.

However, for purposes of standardization or analysis, absolute reflection coefficients must be measured. It might be desirable to plot analyses of value scales on Fig. 47 and for this purpose the illustration has been left reasonably large.

From a practical standpoint, inasmuch as values are judged by the eye, it appears that the common practise of using nine steps in the scale of values is sufficiently complete and quite satisfactory. The suggested standardization of the scale of values is the result of a consideration of all the factors involved and appears to be a simple and satisfactory value scale. If such a scale be used and only relative values are desired the white on the scale can be reduced to the new scale by multiplying by 125. Of course the relative brightnesses remain the same as before. It is hoped that this suggestion may lead to a standardization of the scale of values in absolute units or at least to a closer attention to the consistency and uniformity of the scale of values used by teachers and artists. Whenever it is necessary throughout this book to refer to a scale of values, that represented in Table IV, and by the full line in Fig. 47 will be used as a standard.

In the foregoing discussion no account has been taken of the effect of simultaneous contrast on the apparent brightness of areas. For instance, two grays of equal reflection coefficients (having the same absolute values) appear identical only when their environments are alike. Often the absolute values are of interest, and in such a case the relative or absolute reflection coefficients are compared with the relative or absolute reflection coefficients of the standard scale of values. Very often, however, only the appearances of objects are of interest. In such a case the judgment of values as seen by the eye is the basis of measurement and the values of various objects of different brightness will be found to vary from those that would be obtained by individual brightness measurements on each object which includes the contrast effect due to its environment. These points should be borne in mind in all studies and applications of light and shade. Obviously the effect of contrast is of high importance in the production of a standard scale of values. Theoretically each value should be surrounded by a field of the same brightness, but this is impossible when constructing a scale. If a medium gray be used as a background, certain practical difficulties will be overcome. For instance, in printing or painting a scale of values the chief difficulties lie in obtaining the pigments for the two ends of the scale, namely black and white. The black pigments obtainable reflect considerable light and the white pigments absorb some light. By using a medium gray background for the value scale the black appears 'blacker' and the white appears 'whiter.' White backgrounds are usually used and there is no serious objection to them, but it appears that a desirable background for a standard scale of values is a medium gray. There is no great difficulty in obtaining a white paper or pigments having a reflection coefficient of 0.8 for one end of the value scale, but it is very difficult to obtain a black with a reflection coefficient sufficiently close to zero to be satisfactory for the other end of the scale. For this reason a white background is welcome, owing to the 'blacker' appearance of one extreme of the scale due to the effect of simultaneous contrast between the B value and the white background.

The effect of environment upon the apparent brightness or value of an object is very simply shown. Take three neutral papers, namely black, medium gray, and white, and cut a clean hole of the same size in the center of each. From a paper of any reflecting power from white to black cut three small pieces larger than the holes cut in the other papers. Place one of these three identical specimens underneath the black, gray, and white papers so that they are visible through the holes. When all three specimens are lying flat upon a surface which receives uniform diffused light, compare the apparent brightnesses of the three identical specimens amid the three different environments. They will not appear alike. The effect of simultaneous contrast on the appearance of neutral as well as colored objects is worthy of a great deal of study by actual experimentation, because the importance and magnitude of these effects are not fully appreciated without an acquaintance gained by such a procedure. In fact the importance and magnitude of the effect of simultaneous contrast or the effect of environment will continue to be more and more appreciated by the student for many years.

Inasmuch as the scale of values is a scale of brightnesses, it appears of interest to discuss brightness and its measurement. Brightness may be expressed in terms of the luminous intensity per unit area of the surface projected on a plane perpendicular to the line of sight, and including only a surface of dimensions negligibly small in comparison with the distance to the observer. It is measured in candles per square centimeter, square inch, etc., of the projected area. The normal brightness is the brightness taken in the direction perpendicular or normal to the surface. In the case of perfectly diffusing surfaces the brightness is always the same, regardless of the direction from which the surface is viewed. Brightness is usually measured by means of a photometer which compares the unknown brightness with a standard of known value. Sometimes brightness is expressed in apparent foot-candles or apparent meter-candles. Such a unit is readily comprehended by those familiar with illumination intensities. A brightness of one apparent foot-candle is taken as the brightness of a perfectly reflecting and diffusing surface illuminated to an intensity of one foot-candle. A very useful unit of brightness is one recently adopted by the Illuminating Engineering Society called the 'lambert' which is the brightness of a perfectly diffusing surface radiating or reflecting one lumen per square centimeter. For most purposes the millilambert (0.001 lambert) is a more practical unit. For readily transforming one unit in terms of another, the data in Table V are presented.

TABLE V

Photometric Units

1 lambert = 0.3183 candle per sq. cm. = 2.054 candles per sq. in.
1 candle per sq. cm. = 3.1416 lamberts.
1 candle per sq. in. = 0.4868 lamberts = 486.8 millilamberts.
1 spherical candle-power emits 12.57 lumens.
1 foot-candle = 1 lumen incident per sq. ft.
1 lux = 1 lumen incident per sq. meter.
1 lambert = 1 lumen emitted per sq. cm.
1 lumen emitted per sq. ft. = 1.076 millilambert.
1 millilambert = 0.929 lumen emitted per sq. ft.
For the last three cases perfect diffusion is assumed.

It is out of the question here to enter into an elaborate discussion of the measurement of brightness. Such discussions will be found in treatises on photometry and illumination, and further definitions will be found in the late reports of the Committee on Nomenclature and Standards of the Illuminating Engineering

Society published in the Transactions of the society. Only the essentials have been presented in the foregoing, but it might be well to add that brightnesses or values are the visible results of illumination. In other words, in order to distinguish between illumination and brightness the former may be considered the cause and the latter the effect. The brightness of a surface is related to the illumination, or amount of light flux falling on the surface, through the reflection coefficient of the surface; that is, areas differing in reflecting power will appear of different brightnesses even under the same intensity of illumination.

CHAPTER VI

THE INFLUENCE OF COLOR

The fact that the brightness and the hue of a given colored object are not invariable, but depend upon the spectral character of the illuminant, complicates the science and art of light and shade very much. This phenomenon can be demonstrated very readily by comparing the appearance of a colored pattern or painting under ordinary artificial light and under daylight. It is well known that colored fabrics appear different in hue under these illuminants, although the fact that the relative brightnesses of colored objects vary with respect to each other under different illuminants has not received much attention. Many of these facts have been illustrated and discussed elsewhere,[1] but a brief discussion will be presented here.

In order to understand why the brightnesses of two different colors cannot in general bear the same relation to each other under different illuminants it is necessary to consider why an object appears colored. A white or gray object does not appear colored when illuminated by noon sunlight ('white' light), because it reflects equal amounts of the incident visible radiation of all wave-lengths. In Chapter II, in the discussion of the physics of light, it was noted that an incandescent object such as the sun emitted light-waves of many wave-lengths or frequencies. The eye is sensitive to a certain range of these wave-lengths, each train of light-

---

[1] Color and Its Applications, D. Van Nostrand Co., New York.

waves producing a characteristic sensation of color depending upon the wave-length or frequency. When a white or gray surface is viewed under an ordinary illuminant the appearance of the surface will be that due to the combined color sensations aroused by the light-waves of many wave-lengths contained in the illuminant. Under noon sunlight the white or gray surface appears white or gray respectively, and under most artificial illuminants the appearance will be yellowish white or yellowish gray respectively. The latter is due to the relatively greater amounts of light-waves producing the sensations of yellow, orange, and red, present in the artificial illuminant. When the light-waves are permitted to impinge separately upon the retina, as is the case when viewing the rainbow, the individual color sensations due to light-waves of different wave-lengths or frequencies are experienced. Various means for separating or decomposing light into its component light-waves are available, such as the prism and the diffraction grating. In the case of the rainbow the raindrops separate the light-waves by refraction.

Various light-waves can be separated by selective absorption or transmission; that is, a colored fabric appears colored because it has the property of reflecting light-waves of certain wave-lengths to a greater degree than others, and a resultant color sensation is experienced. For instance, a red fabric has the ability to reflect only red rays and therefore only a red sensation is produced. The appearance of this fabric is the same as that of a white paper illuminated by an illuminant consisting only of the red rays corresponding to those reflected by the red fabric. If no appreciable amount of red rays were present in the illuminant, as in the case of the mercury arc, the red fabric would appear black. A white paper would be bluish in appearance when illuminated by light from the mercury arc, in both cases the resulting appearances being due to the combined effect of the color sensations produced by the individual light-waves reaching the eye. This is an extreme example of a change in the relative brightnesses of two colored objects under different illuminants.

Another factor, namely the spectral character of the illuminant, must be considered. This can be shown best by means of Fig. 48, in which the spectral distributions of energy in various illuminants are presented. The wave-lengths are given in terms of the usual unit, μ, representing the micron or one ten-thousandth of a centimeter. The chief colors of the spectrum are found in position on the upper scale. It is seen that the ordinary artificial illuminants contain relatively more yellow, orange, and red rays, and relatively less green, blue, and violet rays than sunlight or skylight. For this reason it is obvious that the reflection coefficient of a colored object is not constant, but depends upon the illuminant, and that the reflection coefficients, and therefore the relative brightnesses of colored objects, vary with respect to each other under different illuminants. The heavy vertical lines represent the energy line-spectrum of the light from the mercury arc. Obviously, if a colored fabric reflected only light-waves of wave-lengths other than those represented by the heavy vertical lines the fabric would appear black under the mercury arc, owing to the absence of any reflected light. This is true of a red fabric under this illuminant.

On studying the spectral distributions of energy in the various illuminants presented in Fig. 48, it is obvious that a series of colored surfaces will vary considerably in brightness under two different illuminants. This is shown in Table VI. A series of papers of fairly pure or saturated colors was illuminated by daylight entering a window and the reflection coefficients were determined. The same procedure was carried out when

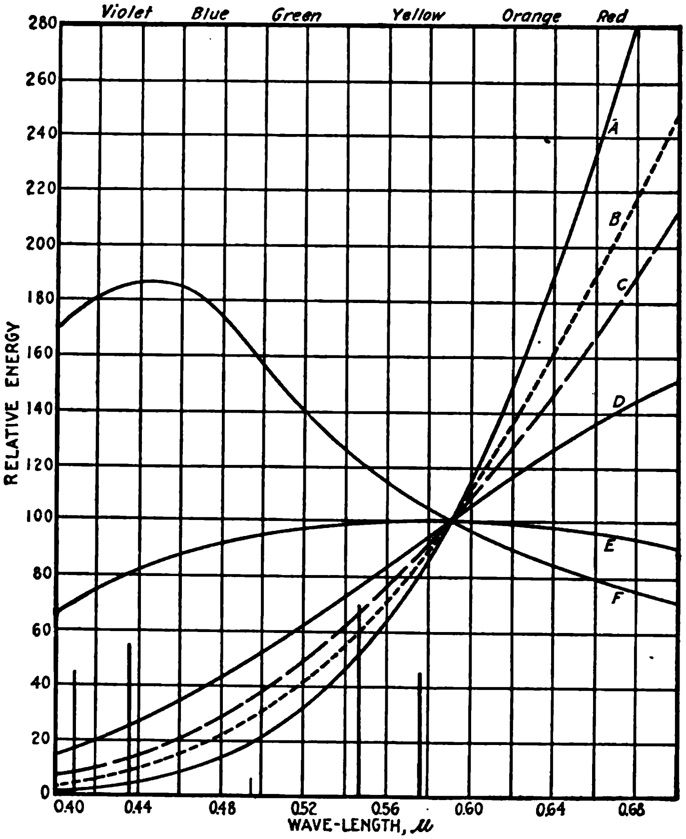


Fig. 48 — Spectral distribution of energy in various illuminants.

A, kerosene flame.
B, carbon filament (3.1 w. p. m. h. c.).
C, tungsten filament (7.9 lumens per watt).
D, tungsten filament (22 lumens per watt).
E, sunlight. F, skylight.

the colored papers were illuminated by the light from a tungsten lamp operating at 7.9 lumens per watt. A considerable difference in the reflection coefficients or relative brightnesses (values) under the two illuminants is to be noted. It is seen that the reflection coefficient of the white surface is constant, but this is not true of any of the colored surfaces. In general the colored papers reflecting predominantly the longer light-waves (red, orange, and yellow) were brighter under the tungsten light than under the daylight. Those which reflect the shorter light-waves (green, blue, and violet) predominantly were brighter under the daylight than under the light from the tungsten lamp. The changes

TABLE VI

Effect of the Illuminant on the Brightness of Colored Papers

Colored paper	Reflection coefficient for		Value under		$\frac{R_T}{R_D}$
	Daylight	Tungsten light	Daylight	Tungsten light	
White diffusing	0.80	0.80	W	W	1.00
a. Red-purple	.16	.23	LD	D	1.44
b. Deep red	.14	.22	LD	D	1.57
c. Red	.21	.31	D	HD	1.48
d. Red	.19	.24	LD	D	1.22
e. Orange	.38	.48	HD	M	1.26
f. Orange-yellow	.60	.66	L	L	1.10
g. Yellow	.60	.65	L	L	1.08
h. Lemon-yellow	.67	.70	L	L	1.04
k. Yellow-green	.46	.42	M	M	0.91
i. Dull green	.49	.45	M	M	0.92
q. Saturated green	.32	.24	HD	D	0.75
n. Blue	.23	.17	D	LD	0.74
o. Deep blue	.13	.09	LD	B	0.69
p. Violet-purple	.14	.12	LD	LD	0.86
m. Blue gray	.30	.25	HD	D	0.83

in brightness are greatest for those colors reflecting light predominantly near the ends of the spectrum. In the last two columns the values taken from the value scale shown in Fig. 47 and Table IV are presented to show that even though each value represents a considerable range in brightness or reflecting power, the reflection coefficient of a given colored paper is, in some cases, so different under the two illuminants as to place it in two different positions on the value scale, depending upon the illuminant. The ratios of the brightnesses of the colored papers under the two illuminants are shown in the last column, where R_T represents the reflection coefficients of the colored papers for the tungsten light and R_D those for daylight. The letters in the first column, with the exception of q, indicate the catalogue (E. Zimmermann) designation of this series of colored papers. Here is seen abundant proof of the effect of color and the illuminant upon the values or relative brightnesses of colored objects.

The foregoing effects are of importance in the use of color. For instance, a painting having an area of blue sky adjacent to yellow clouds was examined under daylight and tungsten light. The clouds and sky were of equal brightness (value) when they were illuminated by tungsten light, but under daylight the sky was twice as bright as the clouds — a considerable change in relative values. Taking into account, besides this change in values accompanying a change in the illuminant, the shift in hues, it is seen that the proper illuminant for paintings (and many other colored objects) is either natural or artificial daylight, because the paintings are almost always executed under natural light. This point will be discussed further in Chapter X.

In a study of light and shade, colored shadows should receive attention, because they are visible to the close observer almost everywhere. They are especially visible out of doors in the sunlight. Even at midday on a sunny day a shadow on a white surface is decidedly bluish in color as compared with the color of a portion of the white surface receiving light from both the sun and the sky. This is due to the bluish color of the skylight which illuminates the shadows. This effect may be observed throughout Nature and is quite striking in some colored objects. For instance, some green leaves appear blue-green in a shadow as compared to their green appearance in the direct sunlight. Of course the different brightnesses of objects in a shadow and in direct sunlight (the intensity of illumination from the entire sky being sometimes less than one sixth that from the noonday sun) makes it difficult to be sure of the exact change in color. Toward evening when the sun has become quite reddish in color and the illumination due to light from the sky is approximately equal to that from the sun, the colored shadows are quite evident. Now the shadow is a vivid blue or blue-green compared with the reddish purple of the combined light from the sun and sky.

The colored shadows are more difficult to distinguish in interiors, owing to the low brightness of the shadows, but they are often present. The colored walls and ceiling send colored light to the shadows so that the latter are distinctly colored as compared with the portion of the same surface which receives considerable light direct from the light source. When the eyes are carefully screened and a white diffusing surface is used to receive both the shadow and the total light, these colored shadows are visible. A simple method of observing the effects of wall coverings in producing colored shadows is to make the observations at quite a distance from the windows which admit daylight. A striking demonstration in which the same principle is applied is to cast one shadow upon a white surface by intercepting daylight coming through a window and another by intercepting artificial light from a source in the room. The two shadows will not only be colored but will be of different color, illustrating the difference in the color of the two illuminants. In this case one shadow receives only daylight and appears bluish by contrast with the other shadow, which is yellow because it is illuminated only by artificial light. The surrounding surface receives light from both illuminants, and the resultant hue is that due to the mixture of the two illuminants.

In Chapter IV the color effects produced by multiple shadows have been briefly described. Such effects can be utilized in various ways. In some lighting demonstrations with posed models, the beautiful effects of colored shadows were strikingly illustrated. If a subject were flooded with light of a given color from all directions and then lighted by means of a strong directed uncolored light, only the shadows appeared colored and these were of varied brightnesses. By means of rheostats and red, green, and blue lamps, the flood of colored light could be changed at will in hue and intensity with very beautiful results. By changing the position of the directed light other expressions were obtained and the shadows remained colored. It is surprising that colored shadows have not been utilized in artistic stage effects to the limit of their possibilities.

The surface character and color of an object often combine to produce interesting gradations of light and shade intermingled with gradations of color. There are so many conditions of this character encountered that it is quite impossible to describe all of them, but the general principles will perhaps be useful in analyzing such conditions. Light is altered in color when it is diffusely reflected from a colored surface, but that which is specularly reflected from the surface remains unchanged in hue. Inasmuch as most surfaces reflect some light specularly, the appearances of colored objects are complicated. The high-light on a glazed colored object is not colored at all by the object, but partakes of the color of the light source — the high-light usually being the reflected image of the light source. Such objects are exemplified by billiard balls, marbles, and apples. Sometimes the colored surfaces of objects are covered with a thin diffusely reflecting surface. In such cases the appearances are complicated, due to the white veil over the colored surface. The ordinary light and shade effects produced on the white diffusely reflecting layer are superposed upon a colored surface with an intermingling of color with light and shade that requires close observation to analyze. Many cases have been presented to illustrate that a knowledge of the laws of light are very useful in analyzing the appearance of a colored object.

CHAPTER VII

LIGHT AND SHADE IN NATURE

There are many reasons why a study of light and shade in Nature should be profitable and interesting, although one cannot hope to present in a single chapter an exhaustive analysis of light and shade in ever-changing Nature. However, an attempt will be made to discuss the subject from various viewpoints with the aid of data obtained by actual measurement. For a study of light and shade from many viewpoints, Nature is an excellent subject, because its lighting is ever changing and its cloak varies with the seasons.

Nature's light varies in intensity from practically zero to a very high maximum and in distribution from the diffused lighting from an overcast sky to the highly directed lighting on a clear day. Between these latter two extremes are represented an infinite variety of relations of diffused and directed light. Much sculptured art is subjected to this varied lighting, and the effects on the light and shade of these modeled objects furnish interesting and valuable information to the sculptor, architect, and painter, and to those who appreciate such work. The changing cloak of Nature and the effects of many different lightings upon it provide valuable material for the artist and all lovers of Nature and art. The artist has recognized this value, for he spends many hours studying Nature with brush or crayon. Perhaps this brief chapter will be justified if it is the means of convincing others that Nature is a perpetual source of pictorial interest. Nature is a picture gallery containing an infinite number of canvases. For this reason it is interesting and profitable to choose and to study those scenes which are pleasant and those which are unpleasant. Further pleasure and profit can be derived from analyses of these chosen scenes and the results are helpful in many ways.

From the standpoint of vision, Nature affords an especially interesting field for exploration. The eye and the entire process of vision have no doubt been influenced during their evolution by their environment, which has been Nature and Nature's lighting. The activities of modern man are far removed in character from those of primitive man. He is now largely an indoor instead of an outdoor being, and owing to the development of dwellings, even the natural lighting conditions under which man works have been altered greatly. Since the advent of efficient and convenient artificial light sources, man has become to some extent independent of natural light, a considerable portion of his time being spent under artificial lighting. For these reasons it is quite essential that natural lighting conditions be analyzed, hence there are provided other interesting viewpoints from which to study Nature.

It appears of interest to consider briefly the chief sources of light, namely the sun and the sky, and the varied combinations of light from both. Skylight is merely the light from the sun that has been scattered by the particles of ice, water, dust, smoke, etc., in the atmosphere; that is, the atmosphere may be considered as a partially diffusing medium somewhat similar in its transmission characteristics to *c′*, Fig. 2. It is a readily demonstrable fact that an atmosphere containing many fine particles or a solution such as dilute milk transmits light selectively; that is, it does not transmit or scatter all light-waves in the same proportions. The light-waves of shorter wave-lengths (violet, blue, and green) are scattered more freely than those of longer wave-lengths (yellow, orange, and red), the results of this selective scattering by the atmosphere being to make the direct sunlight more yellowish in color at the earth's surface than in the interplanetary space and to make the scattered light — the light from the sky — bluish in color. These results are visible on any clear day, for the sky appears blue and a shadow upon a colorless surface appears bluish in comparison with the sunlit surface, owing to the fact that the former only receives light from the sky while the latter receives light from both the sun and sky. The difference in the color of sunlight and of skylight is more strikingly seen if the two lights are directly compared at about equal intensities on adjacent white surfaces by means of a specially devised apparatus.

For the sake of simplicity the effect of an overcast sky will be considered by means of a hemisphere of uniform brightness; that is, one which emits equal quantities of light per unit area. Of course very few objects outdoors receive light from an entire hemisphere of sky, and on clear days at points where the sun is visible the smaller the amount of sky visible, the smaller is the ratio of the amount of skylight to that of direct sunlight. In Fig. 49 the hemisphere *H* represents the sky, and it is assumed to be of

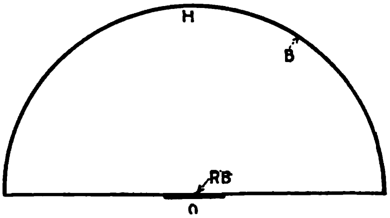


Fig. 49 — Brightness of object, O, due to a hemisphere of uniform brightness, B, equals the reflection coefficient of O multiplied by B.

uniform brightness, *B,* over its entire inner surface. It is readily shown mathematically that the brightness of the object, *O,* is equal to its reflection coefficient, *R,* multiplied by the brightness, *B,* of the hemisphere. If the object were perfectly reflecting, its brightness would be equal to that of the hemisphere. The foregoing is true whether the object is diffusely reflecting like white blotting paper or is specularly reflecting like a mirror. In other words, no object, even when illuminated by an entire overcast sky, can be brighter than the sky. However, when the object receives direct light from the sun, the condition is different. In this case an object sometimes may be as much as six times the brightness of the sky. This is due to the fact that sometimes the illumination due to direct sunlight is greater than five times that due to skylight. Under extreme conditions of deep blue sky and clear noon sunlight, the sun contributes as much as nine-tenths of the total light reaching the earth, but such cases are rare and are usually at high altitudes, where the atmosphere is quite free from dust, smoke, etc. None of the thousands of measurements made by the author on the relative intensities of sunlight and skylight showed that the sun contributed more than five-sixths of the total light reaching the earth's surface.

It is a common but erroneous belief that daylight approaches perfect diffusion in distribution. It is true that for some conditions of natural lighting, namely on days when the sky is overcast, the light is relatively highly diffused compared with many ordinary lighting conditions, but that it approaches perfect diffusion is not true, as will be seen in Fig. 50. Imagine a white diffusely reflecting surface to be placed at the center of the large circle and rotated throughout 360 degrees about an axis perpendicular to the plane of the paper. The length of any radial line drawn perpendicular to the test surface at the center of the large circle to one of the curves represents the relative illumination received by the test surface at that specific position.

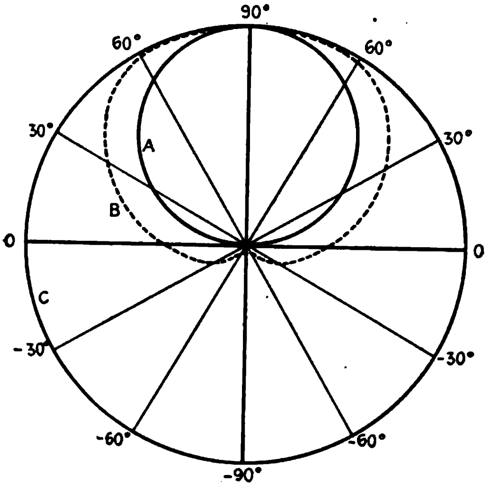


Fig. 50 — Distribution of illumination about a point (center of figure) due to;
A, a point source.
B, overcast sky.
C, totally diffused light.

When the test surface is horizontal and facing upward it is receiving the maximum amount of light from the sky. This value is represented by the vertical line joining the center and the 90-degree point. Curve *A* represents the relative illumination received by the test surface at all angles throughout 360 degrees from only the sun at midday. It is seen that no direct sunlight is received by the test surface after it has turned from the horizontal beyond a vertical position; that is, direct sunlight reaches the test surface as it is turned about its axis for only 180 degrees. Curve *B* was obtained in the same manner on an overcast day when the sky was quite uniformly cloudy. This curve was obtained on the top of a building where the entire hemisphere of sky was visible. It is seen that the illumination does not diminish as rapidly as in the first case as it leaves its horizontal position and that some light reaches it throughout all angles. The surface receives light directly from the sky at all positions excepting when it is horizontal and facing downward. Some of the light that reaches the test surface at any position throughout the lower 180 degrees, represented by the minus sign, is reflected to it by objects on the earth's surface. In this case the roof reflected some light, for it was a dark gray gravel surface. Curve *C* represents the constant illumination which would be received by the test surface at all angles under perfectly diffused lighting. Such a condition is never met under practical conditions, although it is closely approached outdoors on an overcast day when the ground is covered with clean white snow and no obstructions such as trees or buildings are near. Indoors this condition would be approached in a room whose walls, floor, and ceiling were approximately of equal reflecting powers, at a point from which the primary light source would not be visible. Perfectly diffused lighting would be quite unsatisfactory, owing to the difficulty that would be experienced in seeing. Light and shade would play a less important part in vision under these circumstances and color would be relied upon to a greater extent in distinguishing objects. A sphere having a surface of uniform reflecting power would appear as a disk, and if it were perfectly reflecting it would be quite *invisible* under these conditions. Even when the reflection coefficient approaches the highest values ordinarily encountered, any object would be difficult to see under these conditions unless it possessed deep interstices. Even though it were seen, its exact form could not be determined with certainty. While no such extreme condition exists ordinarily, some lightings are bad because they err in this direction. For instance a sculpture gallery with highly reflecting floor, walls, and ceiling is quite unsatisfactory. In general it may be said that directed light is necessary for obtaining satisfactory effects, although the solid angle subtended by the dominating light source and the brightness of the surroundings must be carefully considered if the best results are to be obtained.

Next the combined effect of sunlight and skylight will be considered. For this purpose the brightnesses of a horizontal white diffusing surface and a shadow upon this surface were determined. The light from a clear blue sky does not vary greatly in intensity during a considerable portion of the day. However, the amount of direct light from the sun falling upon a horizontal surface varies from zero at sunrise to a maximum at noon and to zero at sunset. First a theoretical analysis of the lighting conditions on a clear day will be considered. For the purpose of discussion the illumination upon a horizontal surface due to direct sunlight at noon is assumed to be four times that due to light from the sky, and for simplicity the amount of light from the sky is assumed to be constant from sunrise to sunset. The illuminations due to the sun and sky respectively under the assumed conditions are shown in Fig. 51, curve *A* being the constant illumination due to the sky and curve *B* the illumination due to the sun throughout its entire range of altitudes, which is represented on the horizontal scale. Curve *C* represents the combined illumination from the sun and sky. The vertical scale for curve *A, B*, and *C* is on the left of the figure. The broken curve *D* represents the ratio of the combined illumination due to the sun and sky to that due to the sky alone, that is, it represents the ratio of the brightness of the test surface receiving the combined light from the sun and sky to the brightness of a small shadow upon the surface which receives only skylight. In other words, it is obtained by dividing the ordinates of curves *C* by those of curve *A* and the values of this ratio are represented on

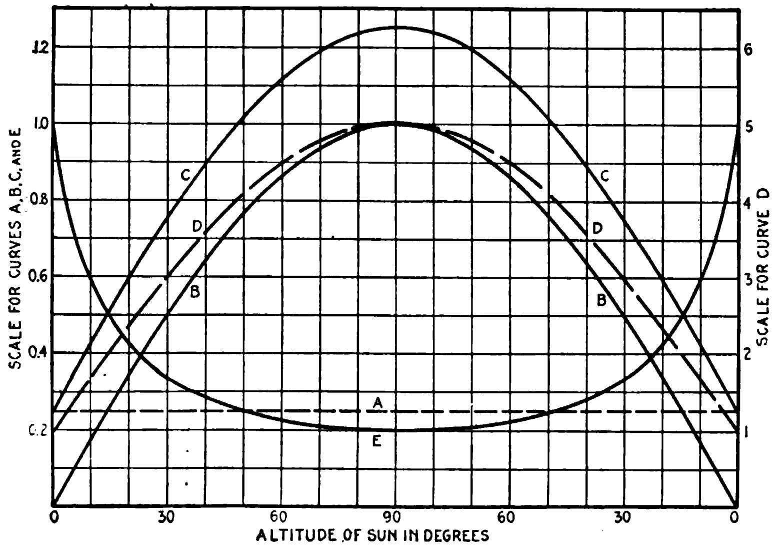


Fig. 51 — Theoretical relations of the luminous intensities of sunlight and skylight.

the vertical scale at the right. Curve *E* is the reciprocal of curve *D;* that is, it represents the ratio of the brightness of the shadow on the test surface to that of the surrounding portion of the test surface which is illuminated by light from both the sun and the sky. Its vertical scale is on the left of the figure. While natural conditions will not be found to be so uniform throughout an entire day, the data shown in Fig. 51 are interesting and useful for obtaining an idea of the natural lighting conditions on a clear day and one worthy of thorough study. It should be noted, however, that the effect is different on a vertical surface and that surfaces in Nature are oriented in all possible directions. The general principles apply to all objects, but it is well to study the effects of surfaces differently oriented. The results for a surface at a given position can be readily obtained from Fig. 51

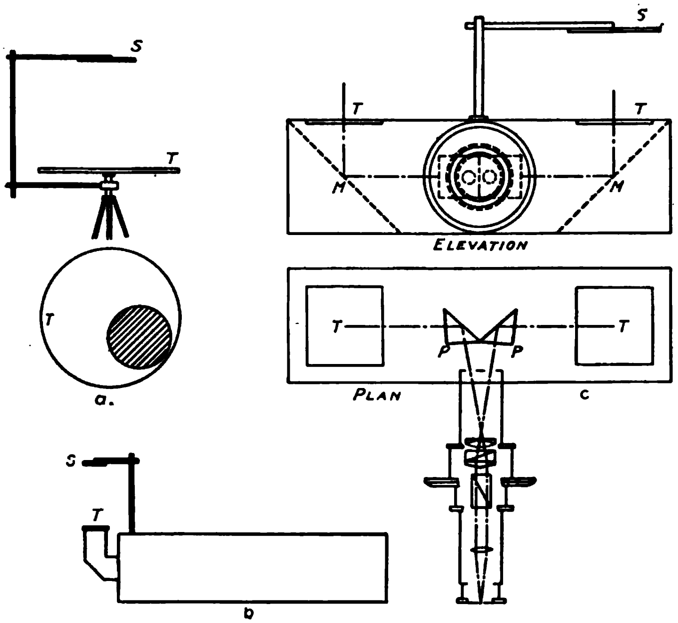


Fig. 52 — Devices for determining the percentage of skylight in the total light reaching a horizontal surface.

by shifting curve *B* to the right or left by a proper amount. These computations assume that the intensity of direct sunlight is constant throughout the day, which obviously is not true.

On a great many days the brightness of a white diffusing surface and of a small shadow upon the surface were measured by means of a photometer and the apparatus shown in Fig. 52, and other data were obtained from the roof of a building at a point from which the entire hemisphere of sky was visible. (Several different devices were used at different times in obtaining these data.) A white test surface, *T,* was maintained in a horizontal position and a small black disk, *S,* was placed a foot or more above it as shown in *a,* Fig. 52, in such a position (which was altered from time to time) that its shadow was cast upon a portion of the white surface. By means of a photometer the brightness of the shadow was determined, which in reality was a measure of the intensity of illumination on a horizontal surface due to light from the sky alone. In the same manner the brightness of the surrounding horizontal surface affords a measure of the total illumination on the surface due to light from both the sun and the sky. The ratio of the latter brightness to that of the shadow is of chief interest, although from these data it is easy to determine in each case the percentage of the total light contributed by the sun. In *b,* Fig. 52, the shadow-producing object, *S,* is seen suspended over the test surface of a portable photometer. In *c* are shown diagrammatically two views of a simple apparatus especially devised for this work. Two identical test surfaces of ground opal glass, *T,* are placed as shown. By means of the mirror, *M,* and right-angle prisms, *P,* the images of the illuminated test surfaces are reflected so that they can be compared in brightness simultaneously by means of a König-Martens polarization photometer. No other measurements emphasize the extreme variability of the distribution of daylight as much as these. Representative data are presented in Fig. 53 for four characteristic days. The measurements were made continually from 9 a.m. until 5 p.m.

Curve *A* represents the ratio of the brightness of the surface receiving both sunlight and skylight to the brightness of a small shadow on the same surface which receives only skylight on a very clear day. The sky was a deep blue and no definite clouds appeared in the sky during the entire period of eight hours — a very rare condition, especially in the locality where these data were obtained. It will be noted that during midday the skylight was only one-fifth to one-sixth as intense as the combined intensity of sunlight and skylight. In other words, during midday the sun contributed about four or five times the amount of light that the sky contributed on this clear day. At high altitudes on very clear days it has been found that as little as one-tenth the light which reaches the

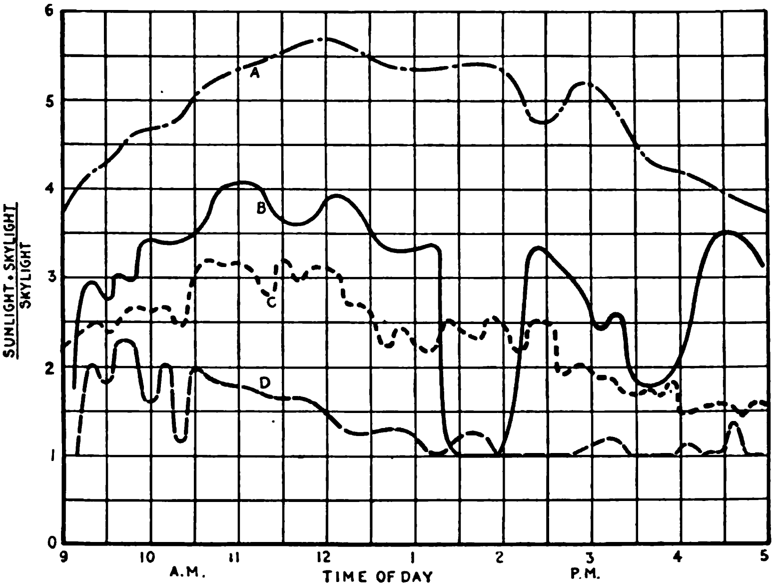


Fig. 53 — Ratio of total illumination on a horizontal surface outdoors to that due to skylight alone on various days.

earth comes from the sky, the remaining nine-tenths coming directly from the sun. The tendency for the ratio to increase toward noon corroborates the conclusions arrived at in the theoretical treatment of the conditions on a clear day, as shown in curve *D,* Fig. 51. It should be noted that these observations did not extend from sunrise to sunset which was the time interval used in the theoretical discussion in Fig. 51. Curve *B,* Fig. 53 represents data obtained on a day during the morning of which a few large cumulus clouds moved slowly across the sky. The sunlight reflected from these clouds increased the relative amount of diffused light, or light from the sky, with the result that the ratio under consideration was smaller than on a clear day. About 1.30 p.m. massive clouds obscured the sun, so that for a time no shadow was perceptible upon the test surface and the ratio became equal to unity. During the remainder of the afternoon the moving clouds caused considerable variation in the ratio. It should be noted that sunlit cumulus clouds vary in brightness from five to twenty-five times that of clear blue sky. Curve *C* represents data obtained on a thinly overcast day. The sun was plainly visible, but the sky was overcast with a thin hazy veil and therefore was brighter than a blue sky, with the result that the relative amount of skylight increased and the ratio under consideration was much smaller than on a clear day. The hazy veil grew thicker and therefore brighter as the day progressed, with the result that the ratio gradually decreased. Curve *D* represents data obtained on a day during the afternoon of which the sky was quite completely overcast. During the forenoon the sky was covered with broken clouds, but these became welded into a uniform covering about noon, with the results as shown. Thus, results obtained on four distinctly different types of days are shown in Fig. 53, and the data give some idea of the tremendous variations in the distribution of natural light outdoors. Absolute intensities of natural light have not been considered in the foregoing, because they are of minor interest. Of course the variations of the absolute intensity of natural light, even during midday, are tremendous. These variations are of interest from the standpoint of interior lighting, but are not of sufficient importance in the general study of light and shade to be considered except casually now and then.

The brightnesses of the various objects that comprise a scene in Nature do not bear the same relation to each other under all conditions of natural lighting. In fact an altered relation is in general apparent with a change in the distribution of natural light. This means that the relative values of a landscape, or of any outdoor scene, are continually changing. Adding to this the continual change in the direction of the shadows due to the shifting sun, the gradual change in Nature's cloak, and the varying intensity of illumination, and it is seen that Nature's appearance is indeed complex. Many actual observations and measurements could be recorded here to advantage, but only those will be presented which emphasize the chief points of interest and afford data helpful to those interested in light and shade.

The difference in the appearance of a landscape on two consecutive days will be shown by actual measurements of brightness. The daylight conditions are described as follows:

August 10. Observations were made at 2 p.m. The sky was practically clear, but very slightly hazy; that is, the sky was pale blue in color and brighter than a deep blue sky, due to a haziness often found in the month of August. Thin clouds were present near the horizon. The total illumination on a horizontal surface due to the sun and entire sky was approximately 6400 foot-candles. The objects studied were not all illuminated by the sun and entire sky. In fact some were in a shadow and most of them were illuminated by only a portion of the sky, as will be indicated later.

August 11. Observations were made at 2 p.m. The sky was entirely overcast. The sun was just visible, but no perceptible shadow was cast by it. The observations were made on the same objects at the same time of the day as on the previous day, all conditions being identical excepting the distribution of light. The illumination upon a horizontal surface (in this case the sun was obscured by the uniform canopy of clouds) was approximately 2350 foot-candles.

The chief objects in the landscape are enumerated and described in Table VII in order to simplify Table VIII, in which the brightnesses are given as obtained on the two consecutive days, which would be designated respectively clear and overcast days. Unless otherwise noted, the objects described in Table VII received light directly from the sun on the clear day. The brightnesses are not given in absolute values but, for the purpose of comparison, the relative values have been computed in each case, the brightness of the horizontal white diffusing surface being assumed equal to 100. For a discussion of the measurement of brightness, the reader is referred to the latter part of Chapter V. In Table VIII the approximate portion of the sky illuminating each object is recorded and whether or not the sun contributed any direct light. Obviously, on the overcast day the sun plays no direct part in the lighting. The brightnesses can be expressed in terms of any other unit by transforming the relative values by the aid of the data presented in Table V at the end of Chapter V. No discussion of the data presented in Table VIII appears to be necessary. It is seen that quite different relative values must be given to reproductions of the same landscape on the two consecutive days during which two distinctly different distributions of natural light prevailed. The measurements were made as rapidly as possible in order to eliminate any large errors due to possible changes in

TABLE VII

Objects whose Brightnesses were measured on a Sunny Day and an Overcast Day respectively. The Brightnesses are presented in Table VIII

Number	Surface
1	Horizontal white diffusing surface (reflection coefficient = 0.863)
2	Shadow on foregoing surface
3	Pavement near building
4	Green grass
5	Green grass in shadow on the sunny day
6	Plowed ground
7	Green foliage of dense woods
8	Gravel roof
9	Gravel roof in shadow on the sunny day
10	Red brick wall of building
11	Red brick wall in shadow on the sunny day
12	Vertical light gray door in shadow on the sunny day
13	Dark weather-stained metal roof
14	Same at specular angle of reflection on sunny day
15	Thin hazy clouds near the east horizon
16	Thin hazy clouds near the west horizon
17	Hazy blue sky in the north
18	Overcast sky in the east near the horizon
19	Overcast sky in the east at 45 deg. altitude
20	Overcast sky in the west near the horizon
21	Overcast sky in the west at 45 deg. altitude

the intensity of illumination. The data for these two days were selected from a mass of data owing to the constancy of the lighting conditions during the periods of observation. It is recommended that the reader carefully study Tables VII and VIII.

TABLE VIII

Brightnesses of Objects described in Table VII on a Sunny Day and an Overcast Day respectively

Surface	Illuminant	Relative Brightness	Illuminant	Relative Brightness
1	Sun and entire sky	100.	Entire sky	100.
2	Entire sky	38.	Entire sky	100.
3	Sun and 0.5 sky	20.	0.5 sky	11.
4	Sun and 0.8 sky	7.5	0.8 sky	7.6
5	0.5 sky	1.7	0.5 sky	5.
6	Sun and entire sky	15.	Entire sky	15.
7	Sun and 0.9 sky	3.	0.9 sky	4.
8	Sun and 0.7 sky	15.	0.7 sky	11.
9	0.7 sky	2.	0.7 sky	8.
10	Sun and 0.3 sky	8.5	0.3 sky	3.4
11	0.5 sky	1.3	0.5 sky	5.2
12	0.5 sky	3.2	0.5 sky	12.8
13	Sun and entire sky	6.	Entire sky	6.
14	Sun and entire sky	12.7	Entire sky	5.7
15		29.		
16		83.		
17		18.		
18		—		40.
19		—		122.
20		—		29.
21		—		103.

In order to illustrate the effect of the two foregoing types of natural lighting upon the appearance of an object, a plaster capital was photographed on the two days, namely the clear day and the overcast day, and reproduced in Fig. 89. The unsatisfactoriness of the highly diffused lighting from an overcast sky and the necessity for directed light if satisfactory modeling is to be obtained are exemplified in these illustrations. It should be noted that, inasmuch as the capital was photographed in a vertical position, the recesses received light from only a small portion of the sky, while the projecting portions received light from a much larger portion of the sky. This would tend toward the results obtained by means of directed light. In fact all lighting, with the exception of perfectly diffused lighting, is more or less directed; that is, there is a dominant direction from which the light comes. The effect of directed light not only involves the direction from which the dominant light comes, but also the solid angle subtended by the dominating source of light and the amount of diffused light reaching the object from other directions.

Inasmuch as the sky is usually a prominent feature in any study of Nature, a few facts regarding it may be of interest. Excepting altitudes near that of the sun, a clear blue sky is usually considerably brighter at the lower altitudes — near the horizon — than at the zenith, due largely to the haziness noticeable at the lower altitudes. This is perhaps always true, excepting when dense clouds, which are not recognized as clouds, are gathering near the horizon. A clear blue sky is darker than an overcast sky excepting in the extreme cases of the latter. A slight haze or thin veil of clouds increases the brightness of the sky very much and therefore increases the amount of light which illuminates many shadows. The color of the sky when clear is more saturated than under any other condition, varying from this deep blue to the neutral gray of an overcast sky. The extreme non-uniformity of the brightness of clear blue or overcast skies is only revealed by measurement. Often a sky which appears quite uniform will vary in brightness at different points by several hundred per cent. A clear sky is usually brightest at those altitudes near the sun, which becomes more marked on hazy days when the atmosphere contains more reflecting particles. This is illustrated by means of Fig. 54, the data shown having been obtained on a clear day when the sky was very slightly hazy. The letters on the four curves stand for east, west, north, and south respectively. The brightness of portions of the sky, about 20 degrees above the horizon and approximately at the four points of the compass, were measured during a day in August from 9 a.m. to 5 p.m. at a point near 40 degrees north latitude. No definite clouds were visible during the period of observation. It will be noted that the brightness of the sky was greatest in the east in the morning and greatest in the west during the afternoon. On a perfectly clear day when the sky was a deep blue, the variations of sky brightness were not so great. The recognized constancy of north skylight is also shown in this illustration. These facts

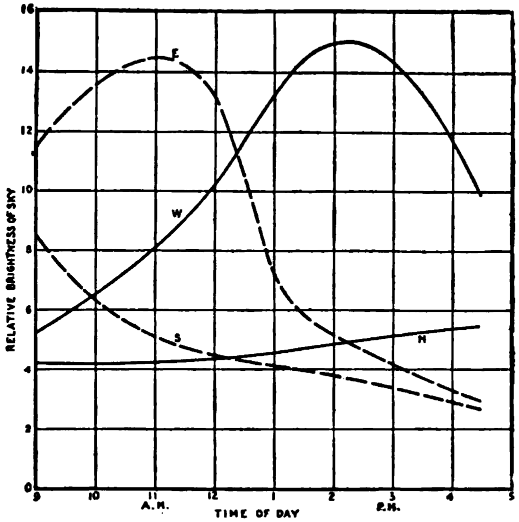


Fig. 54 — Variation of the brightness of the sky on a clear day.

are not of prime importance in the study of light and shade, but do play minor parts at least.

Another interesting viewpoint from which to study Nature is the relation of the distribution of natural light to vision. It is certain that in natural outdoor lighting some of the most pleasing distributions of light are found. The human eye by adaptation has become accustomed throughout the ages to these lighting conditions, which no doubt have played an important part in the evolution of vision. Owing to the lack of a simple method for testing the influence of lighting conditions on vision, at present one must depend largely upon the general impression gained through the visual sense. The general acceptance of natural lighting as the ideal or standard in comparing artificial lighting systems makes it necessary to study the outdoor lighting conditions. The purely indirect system simulates the lighting due to the sky; direct lighting gives the defined shadows due to the sun; and combinations of these two systems imitate more or less closely the combinations of directed and diffused light which are the usual conditions outdoors. It has been seen in this chapter that natural lighting is extremely variable, and in order to imitate natural lighting by artificial means it becomes necessary to choose a definite natural condition as an ideal. No single study of the distribution of light outdoors is expected to be an exhaustive analysis of this very extensive problem, but the author has indulged in various studies of natural lighting conditions outdoors and indoors in comparison with artificial lighting, the results of which have been useful to him. Information gained from these studies is incorporated here and there throughout this book.

It appears of sufficient interest here to record some of the results of a study of the distribution of brightness in Nature, although the study up to the present time is by no means complete. In fact little more has been done than to develop a method and to determine fields for profitable study. Since the work, about to be discussed, was done several years ago by H. E. Ives and the author, many other observations have been made which in general support the conclusions arrived at previously. The study was first confined to the distribution of brightness in certain cases of natural outdoor illumination. The study of this factor was chosen for several reasons, the chief one being that it would yield results of greater interest and usefulness than the analysis of any other single factor. It should be borne in mind that the chief incentive for making this study was to obtain information if possible which would aid the lighting expert in specifying comfortable and pleasing distributions of brightness in interiors.

A photographic method of photometry was chosen because of the rapidity with which the work could be done; thus the brightnesses could be recorded before Nature changed her mood and the photographic negatives could be analyzed at leisure. In order to use the photographic plate in photometry its sensitivity to light of different colors must be like that of the eye. This is not true of any commercial plate, and therefore a filter was made whose spectral transmission was such as to compensate correctly the spectral sensitivity of the plate, so that the plate recorded true values of light and shade. Ordinary photographic plates are not sensitive appreciably to yellow, orange, and red rays. (See Fig. 102.) Panchromatic plates are sensitive to all visible light-waves, but not in the same relative proportions as the eye. One of the latter plates was chosen for use and a filter was made with great care. The spectral sensibility of this plate, of the eye, and of the plate when the filter was used (circles) are shown in Fig. 103. For details of the foregoing procedure the reader is referred to the original article.[1]

Of course the detailed distribution of brightness would be of extreme interest, but could hardly be comprehensive in the present primitive state of the knowledge of what constitutes satisfactory lighting for comfortable vision. If there had been any extremely high brightnesses in the field of vision, detailed brightnesses would have been highly important, but this was not the case. Although such data were obtained, it appeared that the average brightness in horizontal lines would be more readily comprehended at present. The apparatus used was an ordinary camera arranged to revolve on a horizontal axis, as shown in Fig. 55. The normal visual field extends between 70 degrees below the horizontal and 50 degrees above. A panoramic camera would have been ideal for the purpose, but none was at hand, so it was necessary to make six exposures on as many plates, with the camera at various angles in order to include the entire vertical visual field with sufficient overlapping of images. The horizontal field recorded on the photographic plates was considered sufficiently extensive to obtain the desired information. In order to obtain the average horizontal brightness, a cylindrical bottle filled with a solution of chloral hydrate and glycerine, which served as a vertical cylindrical lens, was placed a few inches in front of the camera lens. This lens had the effect of throwing everything out of focus horizontally, leaving the vertical definition practically unaffected. On each plate

---

[1] Trans. I. E. S., 1912, p. 90.

two exposures were made, one without the averaging device and the other with it. The two exposures were recorded and preserved on different portions of the plate by using the two slides possessing different diaphragms. The one with the narrow slot was used for the 'averaging' exposure and the one with the complementary opening for the 'unaveraged' picture. The opaque portion of the latter diaphragm was wider than the opening in the former, so as to leave an unexposed space on the plate (a fog strip) against which the densities of the averaged strip could be measured. The relation of the density of the silver deposit to the brightness recorded and other necessary data for interpreting the results were obtained before proceeding with the investigation of the problem in mind. The procedure will be readily understood on referring to

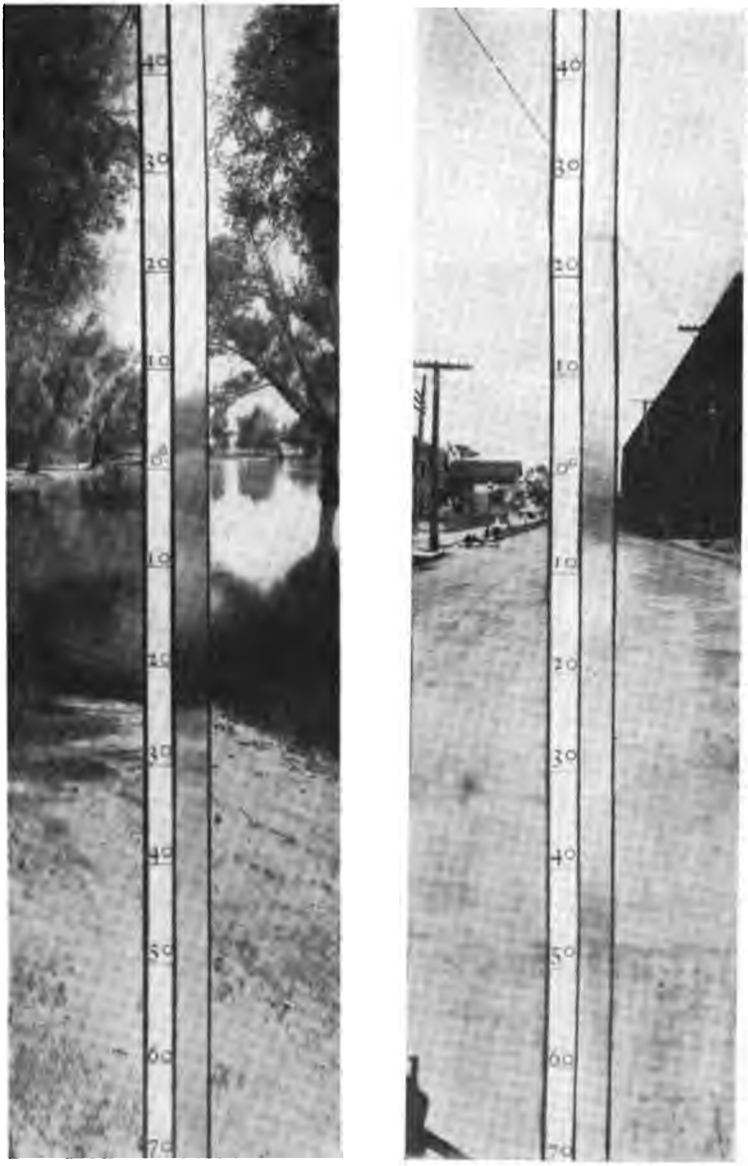
Fig. 55 — Apparatus for studying the distribution of brightness in Nature.

Fig. 56, in which reproductions of two complete sets of photographs are presented. These photographs illustrate the scenes whose brightness analyses are shown respectively in *a* and *h*, Figs. 57 and 58. In the original article the photographs of a number of scenes studied have been reproduced, but they will be only described below. The shaded area in Figs. 57 and 58 represent the relative averaged brightnesses at different altitudes above and below the horizon.

(*a*) This was a scene in a park (*a*, Fig. 56), where the trees practically obscured the zenith sky, but a patch of sky was visible between 15 and 30 degrees above the horizontal. It was late afternoon on a clear day and the sun was at the side and to the rear of the observer. The brightness distribution was very pleasing.

(*b*) This was a typical residence street scene which was not considered pleasant under the strong sun of a clear August day, yet the presence of trees and shade made it endurable. The picture was taken in the morning of a sunny day with a rather hazy sky. The sun was behind the observer. The chief characteristics are the dark point in the horizontal direction and the high brightness of the sky compared with the foreground, although the brightness of the foreground was great enough to be partly responsible for the unpleasantness of the scene.

(*c*) The scene was in a wooded spot late in the afternoon. The sun was shining clearly through the trees on the right and the considerable area of visible sky was dull and cloudy. The spot was a pleasant one, such as might be chosen for a picnic. The most conspicuous feature was the much greater brightness of the sky than the green foreground.



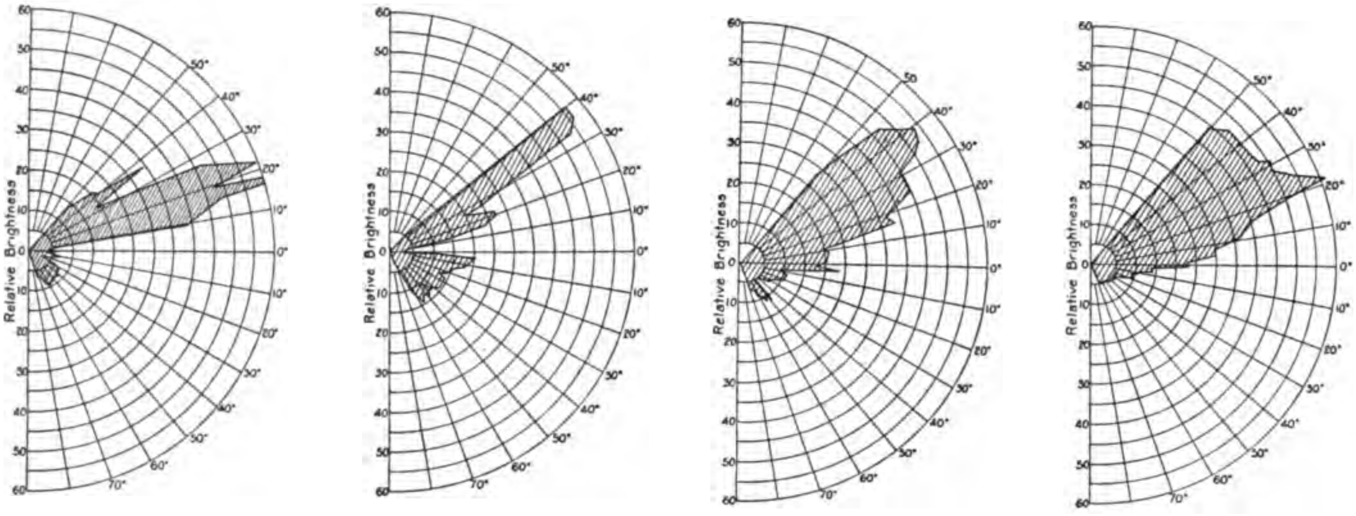
(a) (h)

Fig. 56 — Specimens of photographic data obtained with the foregoing apparatus.

(*d*) The scene was similar to *c* (in fact was adjacent to it), but the observations were made later on the same afternoon after the foreground had passed largely into the shadow of the surrounding trees. With the deep blue and gray of the sky flecked with small bright clouds, the scene was altogether a pleasing and restful one. There is here an even greater predominance of brightness in sky compared with the foreground.

(*e*) The scene was a landscape with a low hill in the middle distance, numerous trees, and a broad expanse of sky. High green grass and dead leaves form the foreground. The sky was clear blue, with a few bright clouds, and the sun was behind the observer. The brightest spot was a small white object illuminated by the sun, and this appeared in the analysis somewhat below the horizontal. The two darkest spots were in the grass near the observer and in the trees near the center of the picture. The sky presented the portion of most uniform brightness and the total brightness above the horizontal was somewhat more than below. Excepting the one bright spot in the foreground, the sky for some distance above the horizon was the brightest spot in the field of view and toward the zenith the sky decreased in brightness. Under these conditions the effect was pleasing. The same scene was analyzed under different conditions as shown in *f*.

(*f*) The scene was the same as described in *e*, but this analysis was obtained for an overcast day. The difference is quite noticeable. From being only a little brighter as a whole than the foreground, the sky is now about four times as bright, and much more of the total flux of light entering the eye comes from it than before. This, together with the shadowless condition, makes the view on the overcast day unpleasant.



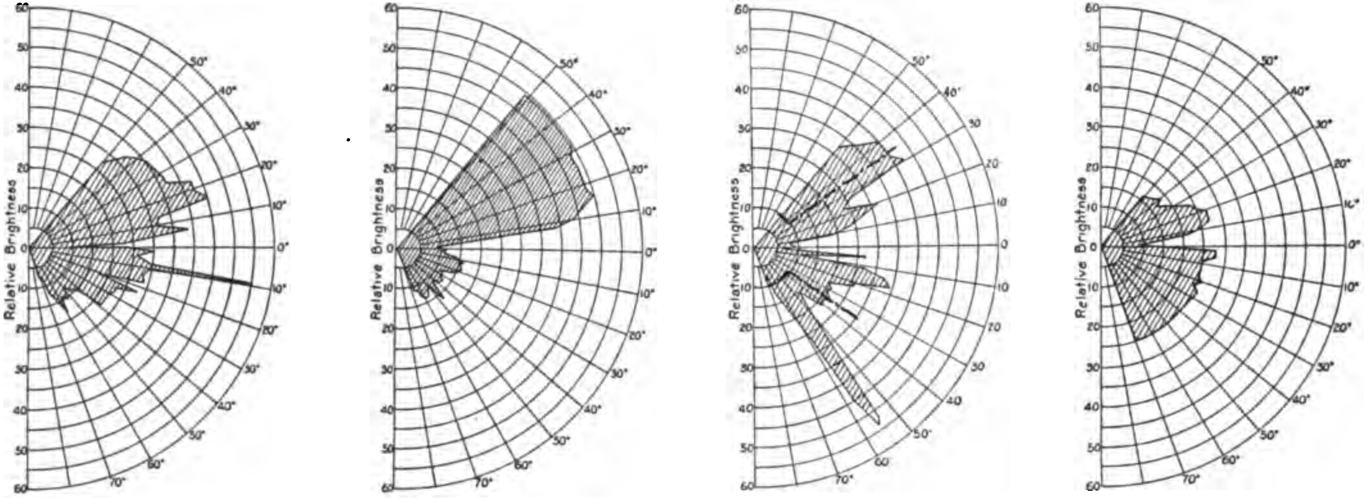
(a) pleasant (b) unpleasant (c) pleasant (d) pleasant

Fig. 57 — Distributions of brightness in various outdoor scenes.

(*g*) This scene was a glaring street and was decidedly unpleasant. The observations were made on a fairly clear day, early in the afternoon, with the sun screened from the observer by a building behind him. The amounts of light flux entering the eye were about equal from above and from below the horizontal, with the brightest spot in the foreground (the sunlit pavement) and the darkest spot in the horizontal direction (a plot of grass and dark buildings). The point of interest about this scene is that when the observer stepped back into a recessed doorway so that the immediate foreground and the upper portion of the sky were replaced by comparatively dark shadows, the impression became relatively quite pleasant. This latter brightness distribution is shown inclosed by the dashed lines in *g*.

(*h*) This was the most unpleasant condition studied. The scene was a glaring paved street in full noon sunlight on a clear day with blue sky. This photograph, which is reproduced in *h,* Fig. 56, was taken to illustrate intense glare from the bright pavement. Here the flux of light from below the horizontal is greater by several times than that from above and the brightest portion of the scene is in the foreground.

As already stated, not many generalizations are warranted before a more exhaustive study is made, but some facts seem to be definite. One is that the eye will tolerate a greater brightness and flux of light above the horizontal than below. Thus the four pleasant cases, *a, c, d,* and *e,* all show this feature, while the street scenes *g* and *h,* with their glaring conditions, show high brightnesses and a relatively great flux of light from below the horizontal. On the other hand, the case of the overcast sky shows that the eye dislikes



(e) pleasant (f) unpleasant (g) unpleasant (h) unpleasant

Fig. 58 — Distributions of brightness in various outdoor scenes.

too much brightness above the horizontal. In fact a feature in each unpleasant case appears to be the presence of large areas of approximately uniform brightness. The eye can tolerate such a condition in the case of the sky, as shown by *a, c, d,* and *e,* but it cannot tolerate uniform high brightness in the foreground. In the case of the overcast sky, *f,* the extended bright area of the sky does not appear to be pleasant in apparent contradiction to the foregoing statement. The explanation seems to be in the fact that in the sky, *c, d,* and *e,* there is considerable variety of light and shade due to foliage and clouds.

In making these observations an effort was made to secure typical outdoor scenes of a well-marked pleasant or unpleasant character as judged by two persons. What constitutes pleasant and unpleasant conditions is of course largely a matter of personal opinion, and it is only personal judgment that is presented here. The aim, however, was to select scenes of such well-marked character that there was little room for difference of opinion. The scenes analyzed above include two pleasant landscapes (*c* and *d*), two views of the same landscape under different conditions (*e* and *f,* respectively pleasant and unpleasant), a shady place in a park (*a,* pleasant), a city street (*b,* unpleasant), and two street views (*g* and *h*) of markedly unpleasant character. In search of these scenes a great deal was learned — perhaps as much as from the pictures themselves. The most striking fact — impressed upon the two observers after many miles of tramping in parks, suburbs, and country — is that Nature is far from uniformly pleasant to gaze upon. In fact it appeared that the chief difference between good and bad in a landscape consists very largely in one thing, namely, the presence or absence of long shadows. The same scene observed at midday with the sun overhead and then pronounced unpleasant or even glaring and ugly, will in early morning or late afternoon be endurable or even charming. Similarly, on overcast days, without the directed shadows due to a bright sun, an attractive landscape becomes dull and characterless. Compared with the sky as a standard, the average brightness of the foreground is at one extreme with midday sun, at the other with the overcast sky. Neither pleases, and from the observations as illustrated in Figs. 57 and 58 it seems probable that a mere mean of the two conditions would introduce the attractive characteristics given by a variety of light and shade under oblique sunlight. This observation has an immediate bearing on artificial illumination, for in nearly every case artificial light, whether direct or indirect, comes from overhead, the very condition under which Nature is least pleasing. Lighting by table lamps or wall brackets — in either case out of the observer's line of vision — would therefore appear to conform more nearly to pleasant natural conditions. This matter is dwelt upon because, while one of the most important factors, it might yet escape the photographic averaging method. As already noted in the discussion of long shadows, the difference between pleasant and unpleasant light and shade conditions seems to be chiefly in the presence or absence of variety. In the best landscapes studied, the ideal condition seems to be a preponderance of brightness in the sky, with the foreground showing varieties of light and shade, occasioned by the direct light from the sun falling rather obliquely. The diffused light of the sky alone is apparently not intense enough or not properly directed to be of itself satisfactory for illuminating the foreground in the presence of an unbroken area of bright sky. The experiment of observing the scene described and shown in *g* from within the shelter of a doorway illustrates some of the conclusions just drawn, for the area of uniformly bright pavement surface is thereby decreased and a pleasing variety of light and shade is introduced.

CHAPTER VIII

LIGHT AND SHADE IN SCULPTURE

The relation of light and shade to sculpture[1] is extremely intimate, because sculpture is almost wholly a pure art of light and shade. It has already been shown that distribution of light greatly influences the appearance of objects, and inasmuch as we are concerned in sculptured art, both with the evolution of the sculptured piece in the studio and with the appearance of the finished work amid another environment, lighting is doubly of importance. It is not generally enough recognized that sculpture is not the mere cutting of form in a given medium, but in reality is an attempt to fix an expression of light. The sculptor sinks hollows and raises ridges not merely to attain these simple objects, but to lead lines of light and shade at will, the lighting in the meantime doing the modeling.

The sculptor paints with his chisel, many of the touches not being given to realize a true form but to produce expression and apparent form with the assistance of his chosen light distribution. His touches are of light and shade. For example, eyes are not represented in perfectly reproduced form; instead the expression of the pupils is obtained by an actual indentation. Ruskin says:

> "In a coarse way, this kind of execution is very marked in old French woodwork, the irises of the eyes of the chimeric monsters

---

[1] M. Luckiesh, Lighting Jour., Mar. 1913; International Studio, April 1914; Proc. Amer. Gas Inst. 1913, 8, part 1, p. 783; Gen. Elec. Rev., 1914, p. 325.

being cut boldly into holes, which, variously placed and always dark, give all kinds of strange and startling expressions, averted and askance, to the fantastic countenances. Perhaps the highest examples of this kind of sculpture-painting are the works of Mino da Fiesole, their best effects being reached by strange angular, and seemingly rude, touches of the chisel. The lips of one of the children on the tombs in the church of the Badia appear only half finished when they are seen close; yet the expression is farther carried, and more ineffable, than in any piece of marble I have ever seen, especially considering its delicacy and the softness of the child features. I know of no example of work in which the forms are absolutely true and complete where such a result is attained. In Greek sculptures it is not even attempted."

The truth of the foregoing expression of a close observer and student of art may be daily corroborated by close observation of sculptured objects; yet, as already stated, few realize that the aim of the sculptor is not to reproduce true form but to produce the appearance of true form and proper expression with the aid of lighting — the master sculptor.

Further, it is obvious that it is of little avail for the modeler to complete his work elaborately unless its impression can be properly conveyed to the spectator. Strictly, vision is the only sense primarily concerned and, as is evident, the lighting effects in light and shade are the means by which the sculptor produces the impression of true forms and their expressions. Therefore the sculptor should carefully consider the lighting of his completed work. If it be an independent production for a gallery, it can be moved to the best available position and the lighting can be properly arranged. Such a plan would be ideal providing nothing prevents carrying it out. However, experience shows that it is seldom possible to light the work in the manner it was lighted while being modeled, even though the sculptor were available to superintend the lighting, which is seldom the case. This illustrates the desirability of a general knowledge of the science of light and shade on the part of the museum director, the sculptor, and others interested in such work. If a given work is a decorative or monumental piece designed for a predetermined position, the modeler should bear in mind the final environment during the evolution of the work. There can be no excuse for not lighting the work during the molding process in quite the same manner that the completed work is to be lighted unless this is impossible. If the piece is destined for the outdoors, obviously it should be modeled outdoors or under conditions quite similar. In this case the sculptor should be familiar with such data as presented in Chapter VII and be prepared to forestall the obliterating effect of lighting on overcast days or the harshness arising from the highly directed lighting on clear days.

In arranging the distribution of light for beginning a piece of work, the sculptor should bear in mind the three chief factors which affect the light and shade of three-dimensional objects. First, the position of the primary or chief light source determines the direction of the cast shadows. The dominating light source may be the sun, the sky, a diffusing skylight, or an artificial light source. Second, the solid angle subtended by the primary light source at the object determines the character of the edges of the shadows and cast shadows. If the primary source be the sun or an ordinary bare artificial source, the edges of the shadows will be sharp, which gives a boldness or severeness to the appearance of the objects. If the chief source of light be a large patch of sky, a diffusing skylight, or an illuminated ceiling subtending a large solid angle at the work, the edges of the shadows will be less sharp; that is, there will be a gradual modulation from light to deep shadow which gives a softness to the appearance of the objects. Third, the brightness of the surroundings (the ceiling, walls, and floor if the work is being done indoors) determines the brightness of the shadows. For instance, if the surroundings be of high reflecting power the amount of light which is diffusely reflected will be large, with the result that the shadows will be brightened by the scattered light which illuminates them. Considerable light finds its way into the shadows by reflection from the adjacent portions of the object which are highly illuminated. The brighter the shadows, the less bold is the effect produced. The relatively greater amount of light in the shadows assists in making daylight more popular than ordinary artificial light, notwithstanding that the light outdoors on a clear day is highly directed, owing to the powerful sun which is practically a point source. The control of the three foregoing factors is not equally easy in each case. It is usually a simple matter to control the general direction of the cast shadows by shifting the position of the primary light source and by properly orienting the work. The angular extent of the primary light source at the work can be controlled in all cases excepting that of the sun. If a patch of sky or a diffusing skylight be used for the primary light source, the solid angle subtended at the work can be varied by varying the effective area of the opening or by moving the work nearer the opening or farther from it. Here it is well to note, as shown in Fig. 108, that the same shadow-producing effect results from a small area of diffusing skylight close to the object as from a larger area when the object is moved a certain distance further away. In some cases large diffusing globes enveloping an artificial light source will produce the effect desired. The amount of light in the shadows can be controlled by varying the brightness of the surroundings and by means of curtains of various reflection coefficients or portable diffusing screens. The problems encountered so far are quite similar to those confronting the portrait photographer, as treated in Chapter XII. The same factors should be carefully considered in sculpture galleries, as discussed later in this chapter.

Obviously no specific rules regarding the character of shadows can be laid down for modeling sculptured objects. This field, like painting and other arts, has a definite scientific foundation, as this treatise attempts to show; nevertheless sculpture cannot be manufactured by scientific formulæ. After the science is revealed, the individual artist is sole master of the procedure. However, it is interesting to note that Flaxman says:

> "Concerning the quantity of light and shadow in a group if the light be one-third and the shadow two-thirds the effect will be bold. If the light be one-fifth and the shadow four-fifths, it will be still bolder and accord with a tragic or terrific action, but the more general effect of sculpture is two-thirds of the light on the middle of the group with a small proportion of very dark shadow in the deeper shadows."

In studying the factors which influence light and shade in modeled objects, many interesting subjects have been used and many effects have been photographed for the purpose of illustrating the various points discussed. The limitations of the photographic processes involved make it difficult to preserve the delicate light and shade effects in the illustrations which are so apparent and convincing to the eye in the originals. For exemplifying some of the foregoing points the head of the father in the Laocoön group (Fig. 82) has been chosen because of its highly expressive character, this group being generally recognized as one of the most expressive among the antique.

It will be noted that the head, which is studied in a number of the following illustrations, faces somewhat upward and is considerably inclined to one side. It is not difficult to light this face in a manner which brings out the expression of pain and suffering and suggests the terrible subject even when separated from the remainder of the group. However, there are few lightings that are at all satisfactory in this case, as is partially shown in Figs. 59 to 69 inclusive. The photographs reproduced in Figs. 59 to 66 inclusive were made amid black velvet surroundings; therefore the light entering the shadows is reflected only from the high-lights on the object in the immediate vicinity. The point sources used (bare incandescent lamps) were three feet distant and in a plane two feet in front of the plane on which the front half of the head was hung. The illustrations are briefly described in the following:

Fig. 59. — Lighted by means of a point source three feet overhead and two feet in front of the plane on which the head hung. Note the sharpness and general symmetry of the shadows. The result is neither artistic nor suggestive of the tragic subject.

Fig. 60. — Lighted by a point source three feet below and two feet in front of the hanging plane. The result is certainly neither artistic nor satisfactory from the standpoint of expression. This result is illustrative of the inartistic and often grotesque effect of the ordinary footlights on most theatrical stages.

Fig. 59 — Above

Fig. 60 — Below

Fig. 61 — Side

Fig. 62 — Side

Different lightings of the Laocoön head by point sources of light.

Fig. 61. — Lighted by a point source three feet on the right side of the face and two feet in front. The expression is placid and very far from one of pain and suffering.

Fig. 62. — Lighted by a point source symmetrically opposite from that used in Fig. 61. The expression, while not sufficiently tragic, is approaching the desired result. In these four cases so far treated, there was more light in the shadows than is indicated. Much of this is lost in reproduction.

Fig. 63. — The right side of the face was lighted by means of a point source in the same position as in Fig. 61. The left side was lighted to an intensity about one fifth as high by means of a diffusing screen subtending an angle of about 90 degrees vertically (45 degrees above and 45 degrees below the horizontal) and about 45 degrees horizontally. This lighting, while illustrating a point, is far from being satisfactory.

Fig. 64. — The lighting is the same as in Fig. 63, with the exception that the diffused illumination on the left side of the face has been increased to approximately the same value as the directed illumination on the right side of the face. Here is a splendid opportunity for comparing the effects of diffused and directed light. There is a striking absence of shadows on the left side of the face, the shade that is present being due to certain elements of the surface being so oriented as to receive a smaller light-flux density.

Fig. 65. — In this case the head was diffusely lighted by means of screens of the same solid angular extent on both sides, the screens being of the same size and relative position as that contributing the diffused light in Fig. 64. The obliterating effect of such lighting is quite apparent. Although lightings are in general more

Fig. 63 —
Point source on the left; diffused light on the right.

Fig. 64 —
Point source on left; diffused light on right.

Fig. 65 —
Diffused light.

Fig. 66 —
Four point sources.

Different lightings of the head of Laocoön.

satisfactory to the eye than to the photographic plate, the lighting here considered was very unsatisfactory to the eye. Notwithstanding the extreme undesirability of such lighting, there are sculpture galleries with walls, floor, and ceiling of high reflecting power and having a large expanse of diffusing skylight in which the effects are not far from this example.

Fig. 66. — The object was lighted by means of four point sources placed symmetrically at the four corners three feet distant and in a plane two feet in front of the hanging wall. The effect is quite as unsatisfactory as that shown in Fig. 65, with the additional annoyance of multiple shadows.

In order to illustrate the effect of three different lighting systems on a sculptured or three-dimensional object, the Laocoön head was photographed in the same position in a room lighted successively by an ordinary direct lighting unit near the center of the ceiling, by an indirect lighting unit in the middle of the room a few feet from the ceiling, and by daylight entering three windows, two being at one side and one in front of the face. The average reflection coefficient of the walls was 0.2 and of the ceiling was about 0.5. The head was hung on one wall about five feet from the floor.

In Fig. 67 is shown the effect of the direct lighting system. The shadows are sharp and bold, though not so dark as is indicated in the reproduction. In Fig. 68 is shown the effect of the indirect lighting system. Here the ceiling is the primary light source which subtends a large solid angle, as indicated by the absence of sharp shadows. The effect is similar to that of a diffusing skylight. A great deal of light enters the shadows, due to a greater amount of diffused or scat-

Fig. 67 — Direct lighting.

Fig. 68 — Indirect lighting.

Fig. 69 — Natural lighting by windows.

Appearances of the Laocoön head in the same position in a room lighted by three different ordinary lighting systems.

tered light present with this system than with the direct system. The general softness is very evident and furnishes an excellent example of a proper distribution of light where softness of shadows is desired. Of course the effect is quite out of place if proper lighting of this particular subject were being sought. In Figs. 67 and 68 the intensity of illumination at the plane on which the object was hung was the same, the illuminants were identical in spectral character, and the photographic exposures were exactly the same. Thus there is provided an excellent comparison of the two extremely different lighting conditions. In Fig. 69 is shown the effect of daylighting through windows, as is common in many interiors. Two windows were on the right side of the face (as indicated by the double shadow visible on the lips) and one was in front. The general unsatisfactoriness of lighting from more than one window is very evident in this case. It is well to note a common difference in the distribution of natural and artificial light indoors. These points will be mentioned later regarding these three illustrations.

At this point it is of interest to show that, notwithstanding light is usually a modeler of form, the distribution of light and shade on an object does not always reveal the true form of the object. This point was illustrated in Figs. 6 and 7, Chapter III, and is further exemplified in the following illustrations. In studying reliefs which are treated later, a striking example of the inability of light and shade to reveal the true form of an object was discovered. A relief and the plaster mold from which it was made were placed side by side in a velvet-lined booth. In Fig. 70 is shown the effect of lighting the relief by means of a point source (bare tungsten lamp) on the right side of

Fig. 70 — A relief.

Fig. 71 — Its mold.

Both were lighted by a bare tungsten lamp at the left and were photographed simultaneously.

the object, and slightly in front, that is, on the left side of the observer as he faced the object. This is evident from the position and direction of the shadows. In Fig. 71 the appearance is that of a relief facing in the opposite direction and lighted from the side opposite to that in Fig. 70. In reality the object shown in Fig. 71 was a mold from which the relief was made and was lighted by the same light source as the relief, the two objects being photographed *simultaneously*. Thus the general shadow effects are practically identical in the two cases, even in the small details. The condition of lighting these two objects from one source at the left of the observer as he faced the objects was such that the light source was screened from view. Furthermore, the black velvet surroundings did not reveal the position of the light source by shadows cast upon it, with the result that when the mold (Fig. 71) was viewed alone, it actually appeared to be a relief lighted from the side opposite to that on which the light source was actually situated. Of course, it is natural that the mold was assumed to be a relief, because the latter is common and the former is uncommon. The two objects were left in the same positions side by side, and photographed while lighted by means of a point source above and slightly in front of the plane on which they were hung. The relief is seen to appear in true form with the shadows cast downward as shown in Fig. 72. The mold actually appeared to be a relief lighted from below, as is seen in Fig. 73, notwithstanding it was lighted from above by the same source that illuminated the relief as shown in Fig. 72. These two objects were photographed simultaneously side by side and received light from the same point source above them. It will be noted that the light and

Fig. 72 — A relief.

Fig. 73 — Its mold.

Both were lighted by a bare tungsten lamp above and were photographed simultaneously.

shade effects in Figs. 70 and 71 are practically identical, yet in Figs. 72 and 73 the effects are quite reversed. Many other identical simultaneous lightings of these objects are of interest, but these are sufficient to show that the distribution of light and shade upon an object does not always reveal its true form. Judgments are influenced by past experiences, and in this case the object illustrated in Figs. 71 and 73 was not suspected of being a mold and not a relief because the relief is by far the most common in objects of this character. Experiments were performed with this mold on many observers, and invariably when the light source was thoroughly screened and the light was not sufficiently intense to reveal the faint shadow cast on the black velvet background the object was thought to be a relief lighted from a position directly opposite to that actually occupied by the light source. When the foregoing precautions were not carefully taken, the observer would usually detect that the object was a mold instead of a relief, although the reasons for this correct conclusion were usually hazy. These experiments illustrate the complexity in the distinguishing of the forms of objects and show that correct conclusions are often arrived at through a subconscious associational mental process.

An interesting and important viewpoint from which to consider light and shade in sculptured objects is the effect of the medium employed in the work. For instance, some marbles are especially translucent and lend themselves to the modeling of human statues because of their similarity to human flesh in translucency. Only a small portion of the light reflected by the human flesh is specularly reflected, the remainder being diffusely transmitted and reflected. The fact that many marbles can be given a matte or velvety surface combined with their translucency makes them satisfactory media for the production of statues of white beings. Metals are not translucent and usually have such smooth surfaces that a considerable amount of light is specularly reflected. The diffuse reflection coefficients of metals used in sculpture (bronze, copper, etc.) are usually low, so that the amount of light diffusely reflected is small. These two conditions combined result in a much greater percentage of the total reflected light being specularly reflected than in the case of plaster and marble. For this reason the highlights on metallic sculptures are much more conspicuous than in the case of the plaster and marble pieces. The metals, however, are excellent media for sculptured works representing a human being with swarthy skin, such as the indian or negro, or for representing the glossy coat of animals having dark fur. By no means is it contended that the fitness of the medium for imitating various objects, as briefly discussed in the foregoing, in any way prevents the artist from displaying his ability in any medium, but inasmuch as the surface character and the medium are highly influential on the light and shade effects, a few illustrations are inserted to emphasize the points.

In Fig. 74 a photograph of Clytie by W. H. Rouchart is reproduced. The soft features, the diffused lighting, and the translucency of the marble all contribute in making the light and shade effects very satisfactory and in producing a harmonious blend of almost perfect congruity. Fig. 75 represents a different view and lighting, somewhat altering the expression and light and shade effects. Compare Fig. 76, a polished bronze Venus by C. G. Allegrain, with the preceding illustra-

(Courtesy of the Metropolitan Museum of Art.)

Fig. 74 — Clytie in marble by W. H. Rouchart.

(Courtesy of the Metropolitan Museum of Art.)

Fig. 75 — Clytie in marble by W. H. Rouchart.

tion. The work is well executed, but the effect of light and shade as conveyed to the spectator by this polished metal is far less satisfactory than that conveyed by the translucent marble of Figs. 74 and 75. Both of the statues are of beautiful women, yet apart from the craftsmanship displayed by the artist, the expression in light and shade conveyed to the spectator is far superior in the case of the marble medium. In Fig. 77, a marble sculpture by George E. Bissell, extreme softness results from the use of marble with a depolished surface, soft features, and highly diffused lighting. In Fig. 78, the Sun Vow by H. A. MacNeil, the bronze medium is well chosen to represent the copper-colored glossy-skinned indian. The high-lights are fittingly conspicuous and the diffusely reflected light is properly suppressed, with a resultant congruity that is pleasing.

In Fig. 79, a bronze statuette by L. Tuaillon, conflicting effects of light and shade are shown. The metallic bronze surface conveys an excellent representation of the dark and glossy coat of the horse, but fails to represent properly the translucent and light skin of the female figure. As previously stated, the character of the medium does not depreciate the skill of the artist, but it does have an important effect upon the entire impression conveyed to the spectator through the highly important factor — light and shade. These illustrations were selected for the purpose of showing the influence of the medium on light and shade effects.

The discussion of light and shade in sculpture so far has been confined chiefly to a consideration of modeling in true proportions. Sculpture, however, is a shaping art intended to express and arouse emotion by the imitation of natural objects in solid form reproduced either in true proportions in three dimen-

(Courtesy of the Metropolitan Museum of Art.)

Fig. 76 — Venus in polished bronze by C. G. Allegrain.

(Courtesy of the Metropolitan Museum of Art.)

Fig. 77 — Mary Justina de Peyster in marble by George E. Bissell.

(Courtesy of the Metropolitan Museum of Art.)

Fig. 78 — Sun Vow in dull bronze by H. A. MacNeil.

sions or in two true dimensions, length and breadth, with a diminished proportion in the third dimension of depth or thickness. Sculpture in the round and in relief are alike to the extent that the characteristics of objects which they imitate are their external forms as defined by their outlines chiefly in light and shade. Solid modeling and real light and shade are enjoyed only by the sculptor among the imitative artists. Outlines or boundary contours the sculptor enjoys in common with the draughtsman and the painter. However, when the work is entirely executed in very low relief, the principle is not that of sculpture, for its effects

(Courtesy of the Metropolitan Museum of Art.)

Fig. 79 — Equestrian statue in bronze by L. Tuaillon.

depend only slightly upon the surface light and shade. In such work the contour is traced by a line of light on the side facing the predominating light source and by a line of shadow on the opposite side. Bas-relief approaches painting and drawing, for in the latter cases the third dimension is dispensed with entirely. For this reason light and shade effects on works done in low relief are not so influenced by the distribution of light as works done in three dimensions of true proportions.

In general low relief is seen to best advantage under lighting so highly directed that many objects molded in true proportions would appear very harsh and entirely too bold. In fact the most striking lighting effects on low relief that have come under the author's observation have been due to the direct light of the sun or of a bare artificial light source. Nevertheless much decorative relief is subjected to highly diffused light from many sources with unsatisfactory results, owing to the tendency toward obliteration. For instance, where relief is employed on ceilings and walls in interiors it would be almost invisible under the highly distributed artificial lighting systems if it were not for the superficial coatings applied, as well as the dust that collects in the interstices. When a tinted superficial coating is applied there is a tendency for thicker layers to gather in the interstices, with the result that a darker tint is produced in them and hence the shadow is preserved to some extent. This, and the dust that naturally gathers in the hollows, tends to neutralize the obliterating effect of light coming from many directions. This is largely a problem for the architect and will be discussed in the following chapter.

Four different lightings of a very low relief are shown in Fig. 80 which illustrate that the direction of light plays only a small part in the expression. The lighting in each case is produced by a point source of light three feet distant and two feet in front of the plane upon which the object hung. The surroundings were covered with black velvet, so that no diffused light reached the shadows excepting that reflected from adjacent high-lights. It is seen with this purely directed light the effects are not harsh or bold as in the case of the sculpture in true proportions, as shown

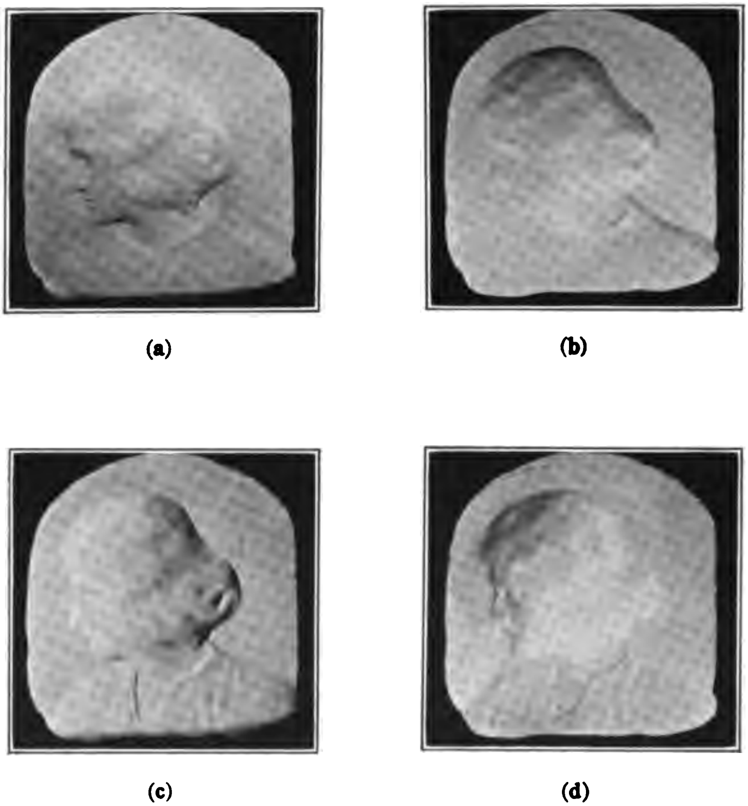

(a) (b)
(c) (d)

Fig. 80 — A relief under different lightings.

in Figs. 59 to 62 inclusive. The obliterating effect of considerable light reaching the relief from several directions was readily demonstrated. In fact, with as few as two point sources illuminating this low relief from opposite sides to approximately equal intensities, it was difficult to distinguish its form. Many experiments and observations indicate that the best effects are generally obtained with low reliefs by means of rather highly directed lighting from sources subtending a relatively small angle at the object.

It has often been noticed that some natural objects when illuminated in a certain manner are suggestive of other objects. These cases are excellent illustrations of the influence of the distribution of light upon an object on its appearance. These examples sometimes furnish humorous aspects, as shown in Fig. 81. On examining a large potato a resemblance to a human face was noticed when the potato was held in a certain position with respect to the light. A plaster cast was made and a number of photographs were taken under different lightings, a few of which are shown in the illustration. Inasmuch as the potato was of the Irish variety, it has been facetiously suggested that the reason for the adoption of this name for a tuber of American nativity has been revealed by this series of photographs. Be that as it may, this illustrates in another manner the importance of lighting in the appearance of objects.

The lighting of the completed sculpture is highly important, as has been seen, because the impression is conveyed to the spectator chiefly by light and shade, which is greatly influenced by the distribution of light. The lighting of a single piece of modeled art is not difficult and can be carried out readily after a consideration of the previous discussion; however, the prob-

Fig. 81 — An Irish potato under five different lightings.

lem of lighting groups of sculpture such as gallery exhibits is an immense one. Judging by the appearance of public exhibits and the varied methods of lighting employed, there is no general agreement as to the best method; furthermore, there is often a plain indication of a lack of knowledge of the simple underlying principles affecting the appearance of such objects on the part of those responsible for their appearance. The ideal lighting is perhaps in general close to that under which the work was executed. This must be true unless others besides the creator of the piece presume to be able to improve its appearance. In gen-

Fig. 82 — The Laocoön group.

eral the judgment of the artist must be accepted as best. Of course this ideal can seldom be realized, owing to the absence of knowledge regarding the environment of the piece during its evolution. However, it is well to bear this in mind and to strive faithfully to determine the best lighting for each work. If the foregoing ideal is to be carried out, obviously each sculptured piece should have a room or alcove by itself. This is usually out of the question in even uncrowded galleries, so that the nearest approach is to furnish each piece with an individual environment as far as possible. It has been said that to do a sculptured piece justice it should be so placed that it may be seen alone. Satisfactory results as to immediate environment have been obtained by means of alcoves as illustrated in Fig. 83. Here there is provided a uniform background so pleasing in comparison with backgrounds consisting of various objects and patterns. By placing the work near the entrance of the alcove or inside of it, the lighting can be controlled to some extent by reducing the effective area of the dominating light source and thus obtaining a degree of directed light that is desirable. The orientation of the statue can be depended upon to some extent for obtaining the desired effects of light and shade. In such alcoves it is of importance to maintain the brightness of the background sufficiently high so that the contrast will not be too great in order to avoid discomforting eyestrain. The alcove idea is shown on a large scale in Fig. 84. Doubtless if the position and extent of the dominating light source and the brightness of the ceiling, walls, and floor are properly controlled, such a placing of sculpture can be made quite satisfactory in all cases.

Another plan aiming to give each piece a degree of exclusive environment is often practicable, as shown in Fig. 85. In this case a uniform background of medium brightness is provided and the sculpture is brightly illuminated. Orientation can be practised to a certain degree in such a case as illustrated in order to obtain the best effects. Where space is limited, the next step is to place the works along the walls, crowding

Fig. 83—The Perseus in the Vatican.

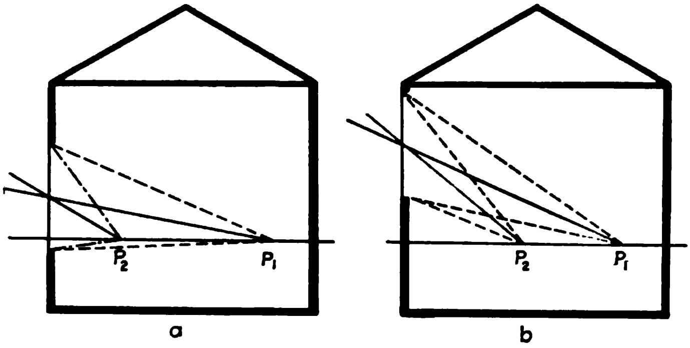
them no more than necessary, but only as a last resort should they be placed about over the entire floor area. Unfortunately there are many examples of this character arising through ignorance or necessity. The placing of sculptured objects having been considered briefly, the next points of interest are the factors which more directly influence the light and shade effects.

As already stated, these factors are chiefly the general direction of the dominant light, that is, the position of the primary light sources, the solid angle subtended by the primary light source, and the reflection coefficients of the surroundings. The first factor determines the general direction of the cast shadows; the second determines the character of the shadow edges; and the third the depth or brightness of the shadows. The last two factors chiefly influence the boldness or softness of the light and shade effects. Leonardo da Vinci enunciated the principle that cast shadows should be equal in length to the objects themselves. This in reality is the law of '45 degree lighting' as practised perhaps more or less unconsciously by many portrait photographers and architects. In general such lighting appears to be best for sculpture, but it is unwise to attempt to formulate a general law for lighting such varied objects as sculpture and for a field so complicated by different esthetic tastes. If it is desired to have the predominant or directed light reach the object at an angle of 45 degrees above the horizontal plane, it is possible to obtain satisfactory results by means of side-light or top-light, providing the dimensions of the gallery are properly related. In order to discuss the subject with greater ease, several diagrammatic sketches of different schemes of day-

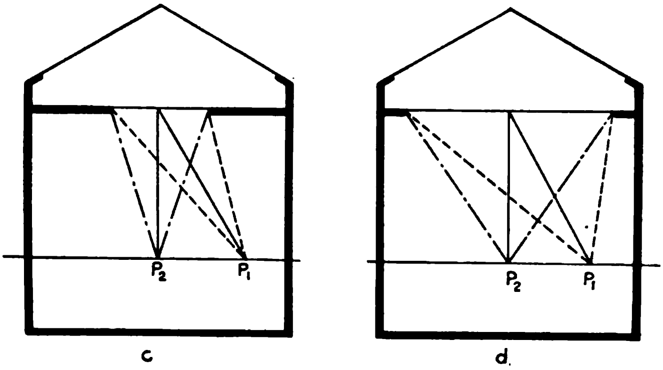
Fig. 84 — The Braccio Nuovo, The Vatican.

Fig. 85 — Sculpture in the Albright gallery at Buffalo, N. Y.

lighting are presented in Fig. 86. Although there are many different methods of obtaining light in sculpture galleries, there are two chief ones, namely side-lighting and top-lighting It is out of the question to describe the many modifications and combinations of these found in practise, so that the general principles will be discussed with the aid of the diagrams shown in Fig. 86 and a few examples from existing galleries diagrammatically shown in Fig. 87. In *a,* Fig. 86, is shown the low side-light, which is usually a clear glass window from which a patch of sky is visible. The full line drawn to the center of the window shows the predominant direction of light at a point, P_1, on a sculptured object. It will be noted that with the low side-light the predominant direction is nearly horizontal. While no doubt some works appear satisfactory under such lighting, the direction is too nearly horizontal to be satisfactory for general application in the lighting of sculpture. The dotted lines show the maximum angle (for the present only one plane being considered) subtended by the light source at the point P_1. Obviously the sky is not seen below the horizontal plane, but the diagram is meant to show the maximum angle that can possibly be subtended by the light source at the point under consideration. If the window is glazed with diffusing glass, this angle shown represents the actual angle. In *b* is shown the effect of raising the window considerably. It is seen by the full line that the predominant light strikes the object P_1 at an angle more above the horizontal than at P_1 in case *a.* The angle subtended by the window opening at the point P_1 is slightly smaller than in case *a*, as shown by the dotted lines. In both examples if the object considered be at P_2 (nearer the window) the predominant



SIDE LIGHT



TOP LIGHT

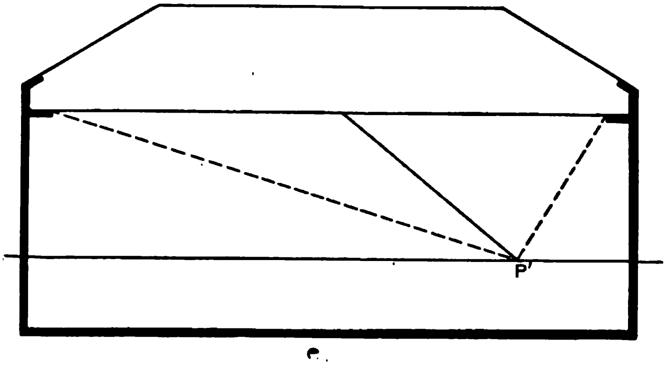


Fig. 86 — Showing predominant direction of light and solid angle subtended by the light source in various types of natural lighting.

direction of the light is found to be more above the horizontal and perhaps more nearly satisfactory in general for sculpture. In both cases the solid angle subtended by the window is greater at P_2 than at P_1. Thus the variations in the shadow effects due to a change in the height of the side-light and the position of the object are shown in these two diagrams.

In *c* is shown the effect of a top-light of relatively small area. The predominant direction of the light is again shown by the full line extending from the center of the sub-skylight to the point P_1. In the case of the top-lighted gallery the sub-skylight is assumed to be glazed with diffusing glass, as is usually the case. Even though no diffusing glass existed in the sub-skylight, practically the same effects would be obtained if no direct sunlight were admitted because now the light-giving area would be a portion of the sky. The same considerations would apply if the direct sunlight were diffused by a diffusing glass in the roof skylight. In *d* is shown the same elevation with the sub-skylight area enlarged. It is seen that the same predominant direction is obtained at P_1 in both cases, *c* and *d*. In the latter case, however, the solid angle subtended by the light source at P_1 is much greater than in *c*. If the point P_2 be considered, the predominant light is now directly downward in both cases, but the subtended angle is different. Few sculptured objects appear well under predominant vertical light.

So far only one plane has been considered, but it should be borne in mind that these openings have another dimension. In order to emphasize this point, diagram *e* is presented. Here is shown the longitudinal dimension of an extensive skylight area whose short dimension might be considered as represented

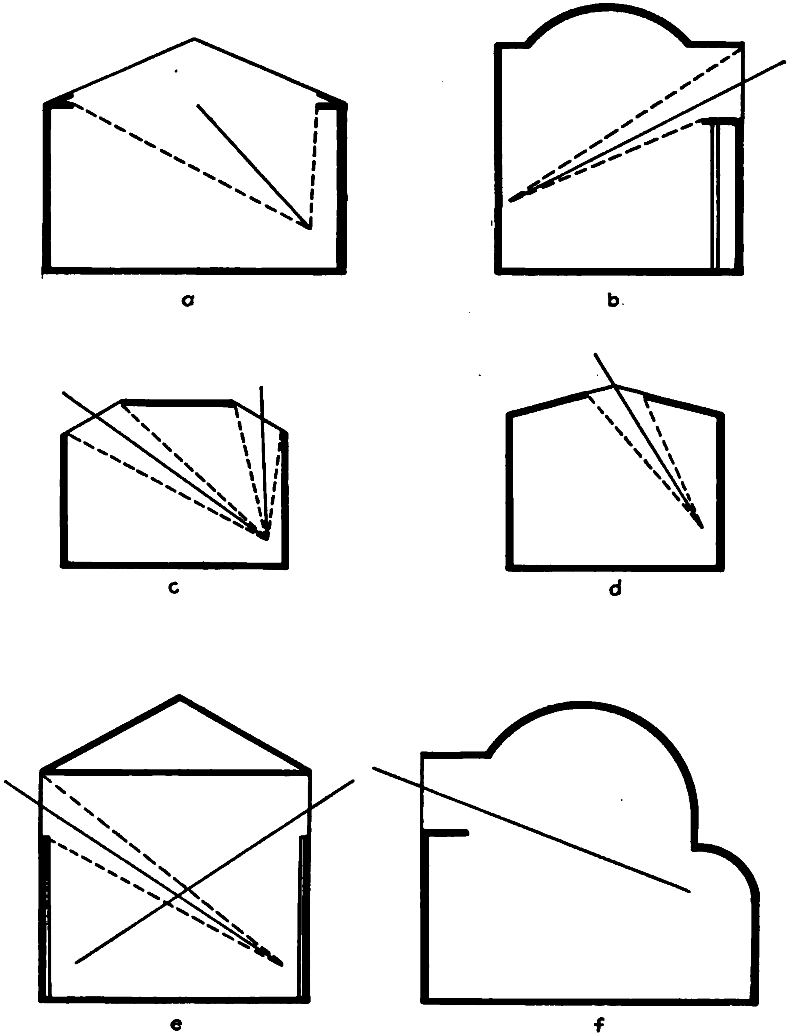


Fig. 87—Examples of sculpture galleries.

by either *c* or *d*. The angle subtended by the light source at any point when considered in this plane for an extended skylight is seen to be very large. When the sub-skylight is glazed with a diffusing glass the effect of a light source which subtends a large solid angle is not quite the same as would be indicated by the large angle, because the distant elements of glass are not furnishing as much light to a given object as nearer elements. This difference is even more marked with partially diffusing glass. Although all the information desired cannot be obtained graphically as shown here, a very great amount of useful data can be obtained by such analyses. It is obvious from these diagrams that actual dimensions are of little moment. Relative dimensions determine the predominant direction of the light and the solid angle subtended by the light source — two vital factors in the realization of satisfactory light and shade effects.

While it is quite outside the scope of this treatise to discuss sculpture galleries in detail or to formulate specific rules for lighting them, a few general conclusions based on experimental facts can be safely drawn. Sculptured objects are so varied in nature and require such different distributions of light for obtaining the best effects that no specific lighting can possibly be the best for all of them. Some objects appear well under almost horizontal lighting, although these are relatively few in number. The predominant light should come from only one light source. For instance, where side windows are used most of the light should reach the object from one window. This can be accomplished usually by deep sills and by the decorative treatment of the interior. The undesirable effects of light from two or more sources are shown in Figs. 66 and 69. Sometimes, when the light is properly balanced and diffused, the lighting from two sources, subtending angles not too small, is satisfactory. It is seen that almost identical results can be obtained by means of side-light and top-light of the proper dimensions and position providing the object is placed in a certain position quite different in each case. That is, side-light cannot be condemned and top-light extolled, or vice versa, because nearly identical results can be obtained under proper conditions. Light on sculpture must have a fairly well-defined direction and in general objects in low relief can usually be made to appear satisfactory in more directed light than sculpture in true proportions. Orientation of the object in any case plays a large part in the effect obtained. In general under ordinary top-lighting the predominant direction of the light varies considerably over the floor space, but the solid angle subtended by the light source cannot be varied greatly by changing the position of the object. With side-lighting as usually practised by means of windows, the effect on the object obtained by varying the position of the object is considerable. By bringing the object nearer the window opening, the predominant direction of the light becomes less horizontal unless the windows be entirely too low; however, this usually results, over a portion of the distance, in increasing the solid angle subtended by the light source or window opening. All of these factors should be considered in arranging the sculptured objects in an exhibit. The underlying principles in the production of light and shade effects are few and simple and therefore should be easily learned.

A point that should be considered is the brightness of the surroundings, because the latter furnish the diffused light which illuminates the shadows. It should be borne in mind that the lighting requirements in sculpture galleries are quite different from those in painting galleries. In sculpture galleries we are concerned with real light and shade as products of the lighting. In paintings the lights and shadows are fairly well fixed and relatively much less affected by the lighting. Highly reflecting surroundings are a disadvantage in painting galleries because of the fatiguing effect upon the eyes and the annoying reflections from the glazed pictures. However, in sculpture galleries sufficient reflected light must be obtained from the surroundings to illuminate the shadows sufficiently. In general even the floor in sculpture galleries should be of moderate reflecting power or the light and shade effects will be too bold. No more specific rules can be safely given, but conclusions can be arrived at by studying existing galleries with the fundamental factors in mind and by means of experiments done on a small but exact scale.

It appears of interest in closing the discussion to note some examples of sculpture galleries in actual existence as shown in Fig. 87. In *a* are shown the essential dimensions of a large sculpture gallery in which the general effects of light and shade on objects near the walls is usually considered fair. The angle subtended by the skylight at the average plane of sculptured objects is seen to be large; in fact so large that one would not expect the effects to be satisfactory. As a matter of fact the chief attraction of such lighting is its uniformity which is essential in a crowded gallery. In *b* is shown a gallery with a small high side-light. The best effect of course is obtained on the side of the room opposite the wall containing the openings for admitting light. Such a system is wasteful of space although the satisfactory effects obtainable warrant this wastefulness where possible. The opposite wall which is not a satisfactory place to show sculpture can be utilized for cases providing sufficient diffused light reaches it. In *c* is shown a mean between side- and top-light. Such a system should be annoying in some parts of the room owing to a large amount of light reaching the object from what is in effect the same as two or more sources. In *d* is shown a small top-light which has the advantage of admitting light in a definite direction. In *e* is shown an example of high side-light sometimes called attic or clerestory lighting. This is often a very satisfactory method of admitting and controlling daylight. In *f* is shown the alcove scheme, each alcove being lighted from a lunette high in the wall opposite. Thus many variations are found in practise. It would be very interesting to analyze many of these widely different gallery lightings visually, photometrically, and photographically, bearing in mind the factors which influence light and shade effects, namely, the predominant direction of the light, the solid angle subtended by the light source, and the reflection coefficient of the surroundings.

In the foregoing only daylighting has been considered. Little remains to be said about artificial lighting for the same principles apply here with the advantage that artificial light can be more easily controlled than natural light. If the natural lighting under a certain condition is satisfactory, obviously the artificial lighting should simulate the natural lighting. If the latter is not satisfactory, the artificial lighting can be made independently satisfactory by consideration of the foregoing principles. There is one precaution to be considered however, namely, that the artificial lighting should be such as to produce practically the same light and shade effects as the natural lighting if possible, providing the latter is satisfactory, in order to obviate any conflicting effects during the hours that the natural lighting must be reenforced by artificial lighting. In all lighting of sculpture it is necessary to bear in mind the fundamental factors so often mentioned throughout this chapter.

CHAPTER IX

LIGHT AND SHADE IN ARCHITECTURE

It may appear strange that architecture has been treated separately from sculpture because it is in reality sculptured art in three dimensions and therefore its appearance is affected by the same influences that determine the appearance of so-called sculpture treated in the preceding chapter. However, architecture in general is a more or less distinct class of three-dimensional sculpture as compared with the class of sculpture considered heretofore and various conditions are in general different.

Architectural work is nearly always designed for a predetermined and fixed position and, therefore, can not be altered in appearance by changing its position with respect to the distribution of light, as is possible with much sculptured art as discussed in Chapter VIII. Thus the architect is usually responsible for the final effects of light and shade upon his work to a much greater extent than the sculptor. This is true especially with outdoor work and often is true of indoor architecture. Of course the artificial lighting is sometimes altered in such a manner that the resulting appearance of a decorative interior is disappointing to the architect. This emphasizes the need for a correct interpretation of light and shade effects and an understanding of the factors influencing them on the part of the lighting specialist and others as well as the architect. There are plenty of existing cases which emphasize the fact that architects do not always have a thorough acquaintance with the principles of lighting. Many other cases prove that the lighting specialist is often quite lacking in ability to interpret and appreciate the principles of light and shade. Perhaps in no other field of light and shade are there so many examples of opportunities ignored or overlooked as in architecture.

In outdoor work the architect should be acquainted, in more than a vague or superficial manner, with the tremendous variation in Nature's lightings and the resulting effects as treated in Chapter VII. Outdoors the architect must be very resourceful in order to produce a work that will withstand satisfactorily the extreme variations in the direction and distribution of light. He works under the handicap that his lights and shades are not fixed but travel as the sun moves, tending to be too bold on sunny days and threatened with obliteration on overcast days. The architect should think in light and shade and be able to imagine the effects on sunny and overcast days and at different periods of the day and seasons of the year. As Ruskin says:

> "Let him design with the sense of heat upon him; let him cut out the shadows as men dig wells in unwatered plains; and lead along the lights as a founder does his hot metal; let him keep the full command of both and see that he knows how they fall and where they fade. His paper lines and proportions are of no value; all that he has to do must be done by spaces of light and darkness, and his business is to see that the one is broad and bold enough not to be dried like a shallow pool by a noonday sun."

The quantity of shade, whether measured in terms of area or depth, contributes considerably to the power and expressiveness of architecture. A famous critic has stated that no building was ever truly great unless it had mighty masses, vigorous and deep, of shadow mingled with its surface. In architecture there are two distinct styles, one in which the forms are molded in light upon shade as in Grecian pillared temples; the other drawn by shadow upon light as in early Gothic foliation. Outdoors it is not in the architect's power to control the factors involving direction and distribution of light which influence the light and shade effects, but a partial control of these effects lies in the original design. Indoors the lighting is usually under control so that it should be predetermined and considered in conjunction with the modelling, the position and character of the ornamental work, the reflection coefficients of the various large surfaces and the positions of the light sources with respect to them.

The discussion of the art of light and shade in architecture could be indefinitely continued but inasmuch as the author makes no claim to being an authority upon this side of the problem, this portion of the subject is left to others. The object throughout this book has been to bring forth the more readily measured and yet neglected aspect — the science of light and shade. At this point it is well to note again that lighting molds sculptured objects and analysis shows there are three distinct factors in lighting which influence the light and shade effects. First, the direction of predominant light determines the general direction of the shadows. Second, the solid angle subtended by the light source (small in the case of the sun and large in the case of a patch of sky, window, or skylight) at the point in question determines the character of the shadow edges. Usually this also affects the quantity of shadow whether measured in area or depth. Third, the amount of diffused or scattered light determines the brightness of the shadows. Obviously the reflection coefficients of the surroundings determine the amount of the diffused light although outdoors the sky contributes a great deal of light to the shadows. The architect and others responsible for the appearance of architectural work should find it profitable to know the optical characteristics of various surfaces, the simple optical laws, and the effects of various factors in light-distribution in order to analyze effects and to visualize the appearance of contemplated work. Certainly the modelling must be different if a certain expression of a work is to be obtained under a directed light than if it is to be illuminated by a highly diffused light or light from an extended source. All of these principles are discussed in foregoing chapters, therefore only a few examples of the effects of different lightings will be presented here.

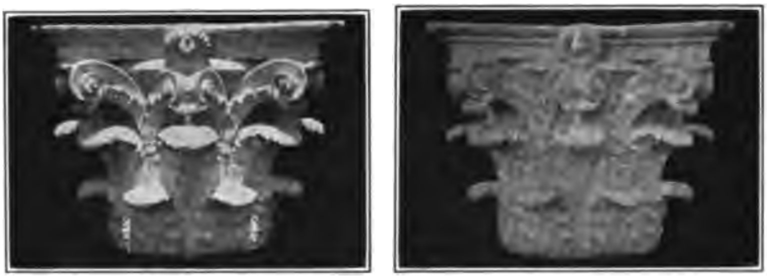
In most of the examples immediately following the objects have diffusely reflecting surfaces. This results, as shown in Chapters II and III, in subdued high-lights as compared with objects having glazed or polished surfaces. The effects are usually more pleasing in architecture although there are many cases where the glittering high-lights furnish boldness or brilliancy that is quite in harmony with the entire composition.

In *a*, Fig. 88, is shown the effect of lighting a Corinthian capital by means of a point source (a bare incandescent electric lamp) three feet above and somewhat in front of the plane on which the object hung. The surroundings were covered with black velvet in order to eliminate the scattered light and to retain only the effect of the directed light. This lighting would not be chosen if an artistic picture of this object were desired although the effect is very much more pleasing than that produced by a point source of light three feet below the object as shown in *b*. In the latter case the light source was in a symmetrically opposite position as compared with *a*. The expression shown in *b* is very unnatural and unsatisfactory and the object appears much different than under the preceding lighting. When this object is lighted from below, and only the object is visible amid black surroundings, the light source being completely concealed, an uncomfortable sensation is experienced. Apparently the observer does not exactly analyze the condition but subconsciously is aware of the shadows being projected upward. This can only result from a light source placed below which is subconsciously recognized as resulting usually in visual discomfort. For instance bright snow on the ground or light from a lantern held in the hand is usually annoying. Thus the psychological impression resulting from the shadows being projected upward causes, through a sympathetic process, a sensation similar to physiological glare. These two widely different expressions, *a* and *b,* are the result entirely of different distributions of light and shade, due to two different, but simple, lightings.

(a) (b)

Fig. 88 — A capital lighted from above and below respectively.

The photographs of the same object, shown in Fig. 89, were obtained in an unobstructed position on top of a building, the object being hung vertically upon a black velvet background. In *c* is shown the effect obtained at noon on a clear sunny day. The direction of the shadows is identical to that shown in *a* but both the shadows and cast shadows are relatively much brighter owing to the great amount of diffused light obtained from a very extensive sky area and the gray gravel roof. The effect is much more satisfactory than in the preceding cases although it is not yet the most artistic obtainable. In *d* is shown the effect obtained on an overcast day. If the object were a sphere there would be very little shade on it and it would be difficult to distinguish its form as shown in Fig. 5. There are no marked high-lights or shadows. The slight non-uniformity that exists is due to the irregular contour which prevents all portions from receiving the same amount of light owing to shielding due to adjacent portions and to the different orientations of the various surfaces with respect to the extended light source. It should be noted that the maximum effective light source was only one half of the visible sky correspond-



(c) (d)

Fig. 89—A capital lighted by combined direct sunlight and skylight outdoors (c); by skylight alone on an overcast day (d).

ing to one quarter of an entire spherical surface. Much of the detail is visible but not as distinctly as under a more directed light. Diffused light is desirable but the amount differs with the effect desired; in other words, shadows are never absolutely black and should not be too bright. The whole effect in *d* is quite unsatisfactory. Thus, in the four illustrations, extreme conditions, two of which are found in Nature, emphasize some of the points already discussed. Owing to the fact that it is the object here to bring out the science of light and shade and inasmuch as artistic tastes differ, no artistic lighting of this object is shown. The most agreeable effect would be obtained by properly directing light from a source subtending a solid angle of moderate size, the predominant direction perhaps being somewhere near 45 degrees with the vertical, and by supplying a sufficient amount of scattered light to illuminate the shadows to a certain average intensity.

In Fig. 90 are shown the various light and shade effects obtained by five different lightings of the same piece of plaster molding. The surroundings were of black velvet and the light sources were bare incandescent lamps about three feet distant and in a plane about two feet in front of that on which the object hung. The effect shown in *a* was obtained by means of a single light source above. This is the best effect of the five characteristic lightings shown. The form is perhaps brought out as well as possible. In *b* the effect was obtained by means of a single source below. The appearance is astonishingly different from that shown in *a* and the form is not satisfactorily revealed. In *c* is shown the result of simultaneously lighting the molding by means of single sources placed respectively above and below. In other words, the result is

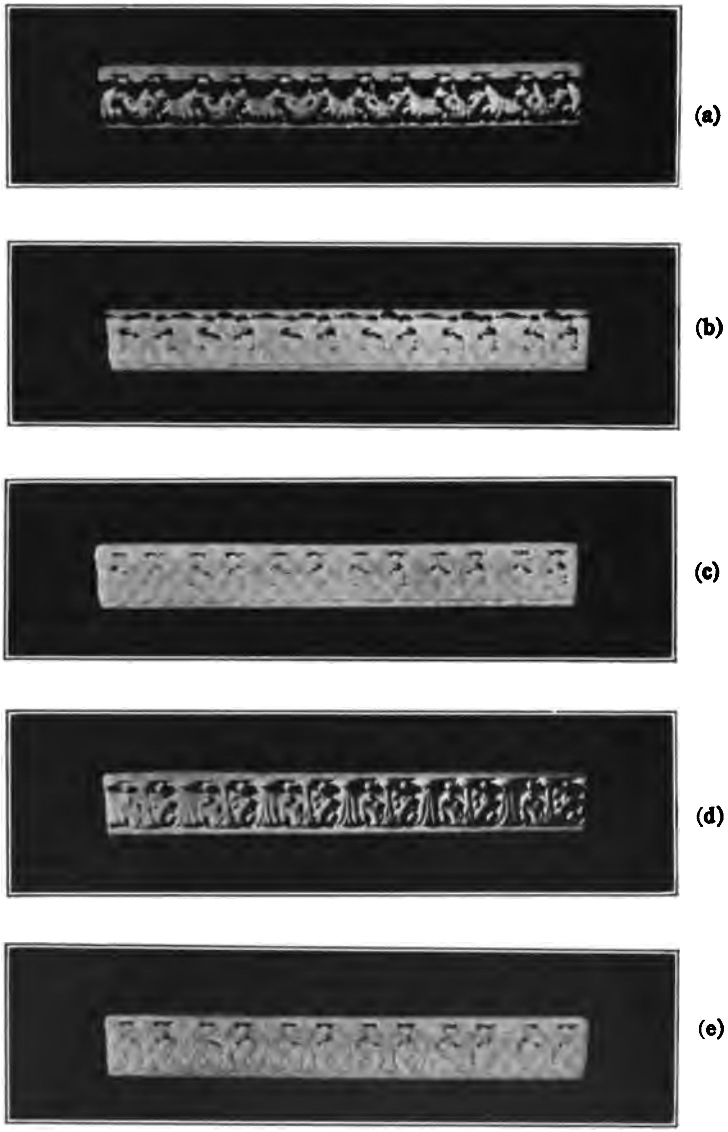


Fig. 90—Five different lightings of the same molding.

the combined effects shown in *a* and *b*. In *d* is shown the effect of a single light source at the side and in *e* the effect shown was obtained by means of four sources placed respectively above, below, and on both sides. It is thus seen that the position of the light source, that is, the direction from which the light falls upon an architectural molding, influences its appearance tremendously.

The effects obtained by five different lightings upon another molding of simple geometrical design are shown in Fig. 91. This molding was hung in the same position as the preceding one and the lightings were as follows: *a,* a single source above; *b,* a single source below; *c,* a single source on the left-hand side; *d,* a single source at the upper left; and *e,* a single source at the lower right. The light and shade effects are quite different in all cases, although owing to the geometrical design there is a similarity in the symmetrical cases. The lightings *d* and *e* are the most satisfactory in revealing the true form of this object and they cause the molding to appear to have depth. These different effects of various lightings upon a molding brings to mind a condition very often noted, namely, the lighting effects upon panels whose outlines are bounded by a molding. Often the predominant light comes from a source in a plane above the panel and the upper and lower moldings appear respectively somewhat like *a* and *b* in Fig. 90, because the molding on the lower edge of the panel is inverted with respect to the upper one. This emphasizes the point that the observer is often depended upon to supply considerable from his imagination. The molding surrounding the panel often appears quite unlike on the four sides and the observer depends upon what he *knows* to be

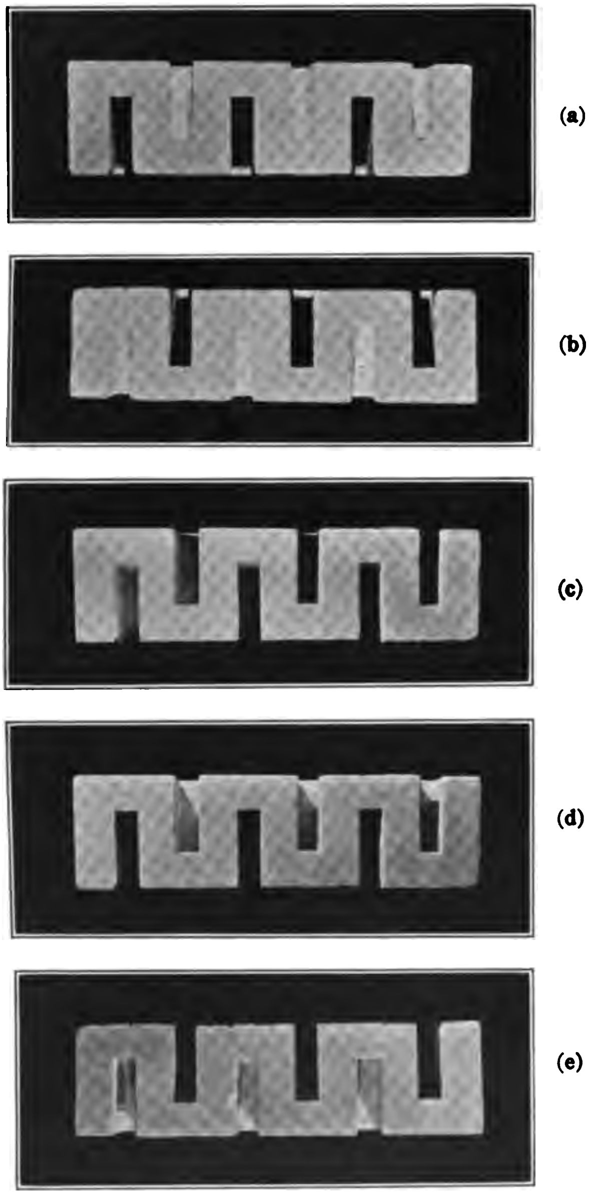


Fig. 91—Five different lightings of a molding.

there rather than upon what he *sees*. An example of the foregoing is often seen in picture frames hanging on the wall.

In Fig. 92 a decorative piece is studied under three lightings. In *a* is shown the effect of lighting by means of a bare incandescent lamp placed in the usual position below. The appearance of this object is practically the same when illuminated from a position symmetrically above. In *b* is shown the effect of a point source at one side and in *c* the effect when the light source is on the opposite side. The difference in these two last appearances is very striking. Note especially the clearness with which the four nodules near the center of the figure are visible in *b*. These nodules practically disappear when the object is lighted by the same bare lamp from a symmetrical position on the opposite side as shown in *c*.

In Fig. 93 are shown three different aspects of a rosette under as many different directions of light. In *a* the effect is produced by a light source at one side; in *b* practically the same appearance is produced by a light source below although the peculiar annoying psychological effect of the shadows projected upward is noted in this case; in *c* the flat uninteresting appearance is produced by means of a light source placed nearly symmetrically in front.

The predominant high-lights, which produce the extremes of brilliancy and somberness depending upon the hue and brightness of the shadows produced on glossy metallic surfaces, are shown in Fig. 94. Owing to the fact that the surface is highly glazed the high-lights (practically images of the light sources) are very bright. The amount of diffusely reflected light being much less than for white surfaces, the high-lights

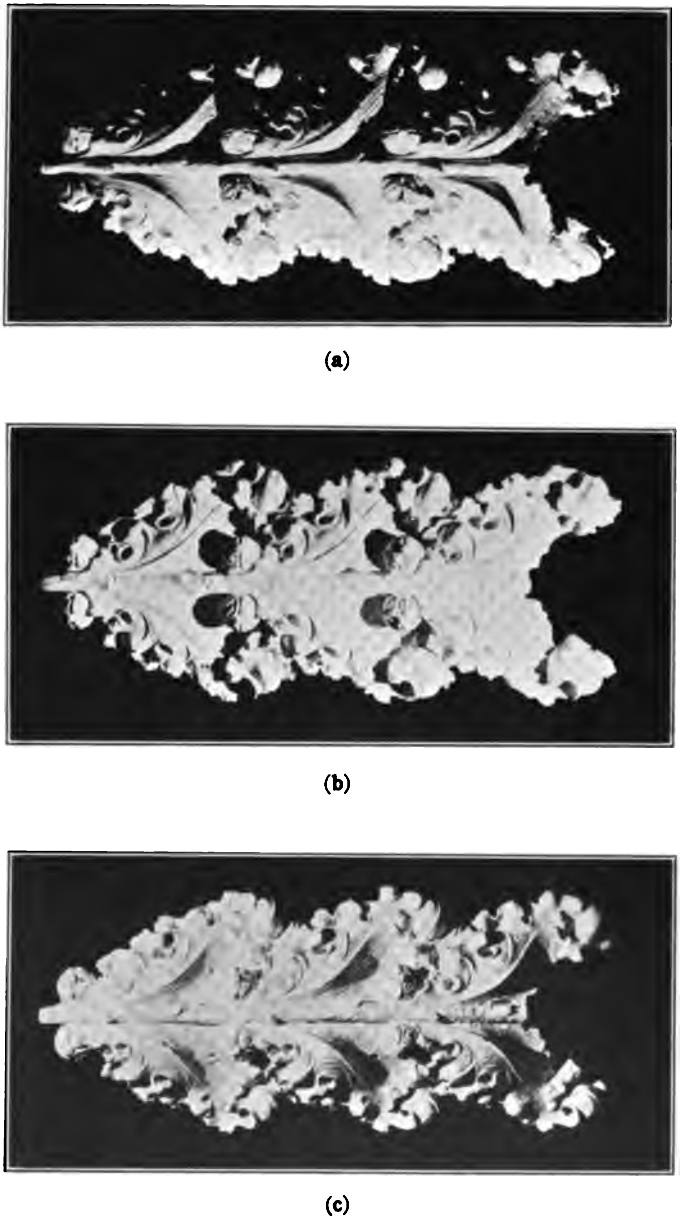


Fig. 92 — Three lightings of the same architectural object.

are very much brighter than the shadows with the result shown. It should be borne in mind that, for a given illumination, the diffusely reflected light from an unglazed object, and consequently the brightness of the portions of the object other than the high-lights, remains practically constant regardless of the character of the light source. However, the brightness of the high-lights (more or less perfect images of the light sources) on glazed objects depends upon the brightness of the light sources. Obviously the intrinsic brightness of the sources of light affect the appearance of such

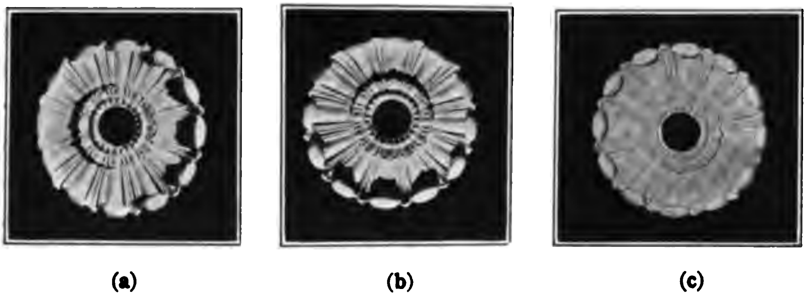

(a) (b) (c)

Fig. 93 — Three lightings of a rosette.


Fig. 94 — Showing the prominence of high-lights on metallic surfaces.

glazed objects to a greater extent than objects having diffusely reflecting surfaces where the preceding effect is absent.

Much of the discussion applying to sculpture as treated in Chapter VIII applies to architecture and therefore will not be repeated here; however, there are viewpoints on the effect of lighting that are sufficiently different to warrant further discussion. Few actual cases will be considered because each is so different from any other owing to the many more or less direct influences. For this reason it appears a hopeless task to consider the many existing cases where the results of the lighting have aided or hindered the architect in realizing the desired effects. Given cases can be analyzed by observation while bearing in mind the general principles underlying the influences affecting light and shade. Natural lighting will not be discussed because it can not be controlled outdoors and only partially indoors. Hence for outdoor work the effects desired must be brought about wholly by design. However, artificial lighting will be discussed somewhat further because it can be made to assist greatly in obtaining the desired effect, or through carelessness and ignorance can be very detrimental. Many points have been brought out in previous illustrations that can be applied on every hand to existing cases. It has been shown that architecture usually is not seen at its best in highly diffused lighting although there are cases where the complete effect is actually beautified by a highly diffused lighting. Rotundas, domes, and such spacious places which no doubt are often to be related in the imagination to the extended space of outdoors, are examples where diffused light, through its partially obliterating and subduing effect, produces the haziness and spaciousness of outdoors. However, where the details of the architecture are of great interest, more direct light is desirable but care should be taken not to counteract the result by reducing the ability to see comfortably owing to glare. From Fig. 88 it is seen that a light source underneath a capital produces a shadow effect which is quite undesirable, yet very often lighting brackets are placed in such positions. If panelled walls are architecturally beautiful, perhaps it would be profitable to arrange the light sources so that the moldings bounding each panel would not appear greatly different on various sides. If very low relief is a keynote in the decorative scheme, light of a correct degree of directedness will bring out the details in a satisfactory manner whereas highly directed or diffused light will be usually unsatisfactory. The general light and shade effect in an interior as a whole is almost entirely dependent upon the lighting system employed. Direct lighting usually results in more light at the lower levels and less at the upper walls and ceiling. This light and shade distribution is somewhat counteracted in many interiors by the greater reflection coefficients of the ceiling and upper walls. With indirect lighting the light distribution is quite reversed with the result that light and shade distribution due to the unequal reflection coefficients is enhanced. The tremendous effect of the distribution of light and shade upon the mood of interiors is but little appreciated. Even in the art of stage lighting the wonderful possibilities of light and shade have been barely touched upon. At this point it is well to note the difference between illumination and brightness. The former involves only the quantity of light reaching a surface; however, the brightness of a surface not only involves the amount of light reaching it but also the reflection coefficient of the surface. Only by means of a thorough knowledge of the influential factors can complete harmony be attained.

Inasmuch as it is the intention here to present only the science of light and shade, the object has been fulfilled after presenting the general principles. However, a few unusual examples of lighting as an aid to architecture will be presented. These illustrations also show the possibility of increasing the actual hours during which beautiful works may be appreciated. Man's activities have changed very much since the advent of comparatively efficient artificial light. At present a considerable portion of his activities extend hours after sunset and the working hours of many persons are such that recreation and opportunities for seeing the beautiful things about them are only available after natural light has waned. For this reason the lighting of architectural work is welcomed by many. A few examples of artificially lighted exteriors will be presented for the purpose of further illustrating the relation of lighting to light and shade effects in architecture. In the last chapter several examples of interior lighting and a further discussion of architecture will be found of interest here.

In Fig. 95 is shown the effect, upon a characteristic style of architecture, of flood-lighting by means of incandescent lamps in projectors placed upon a building on the opposite side of the street. The light comes from above the horizontal and produces a satisfactory appearance. If it were possible to place the light source somewhat higher it might appear that a more artistic effect would be obtained. However, it should be remembered that the shadows under such artificial lighting can never be as bright as under the diffused light from the sky and immediate surroundings in the day-

Fig. 95 — Satisfactory lighting of an exterior.

time so that a too vertical direction of the predominant light must be avoided in order to prevent too much shadow. Thus perhaps it is safe to state that in such styles of architecture as represented in this case, the predominant light should come from nearer a horizontal direction than would be satisfactory during the day in order to prevent the result from being too bold. As a whole the effect is quite pleasing. Mistakes have been made in attempting to light such an exterior by projecting the light upward from posts placed at the edge of the sidewalk. The effect is unnatural and annoying, as shown in Fig. 88, and quite in conflict with that desired by the architect or ever obtained on a sunny day for which perhaps the work was designed.

In Fig. 96 is shown an exterior of an extremely opposite character. Even on a sunny day little shade is visible on such a plain exterior. When lighted from a horizontal position as is the case in this illustration, practically all the architectural details are brought out as well as though the light fell from an angle above the horizontal. The keynote of such an exterior is plainness or flatness and the horizontal artificial lighting is satisfactory.

In Fig. 97 is an illustration of the famous tower of the Woolworth building, a striking Gothic structure, illuminated by artificial light under the supervision of H. H. Magdsick. The only practical method of lighting this building was found in projecting the light upward. The angle at which the light was projected varies for different parts of the tower from horizontal to nearly vertical, the lighting units being supported by both the tower and the main building. Owing to the absence of any portions that project very much, the effect of lighting from below the horizontal is on the whole quite striking and satisfactory. The tower is visible for many miles as a beautiful decorative shaft and represents perhaps the most striking exterior so far illuminated externally by artificial light. The intensity of the illumination increases toward the top and by concealing the lighting units and projecting the light from different angles, the sparkling effect superposed upon the cream terra cotta surface intermingled with

Fig. 96 — A satisfactory example of horizontal flood-lighting.

the touches of blue, green, red, and buff makes the whole a beautiful spectacle.

In Fig. 98 is represented the effect of lighting the well known Statue of Liberty in New York harbor. This is a case of spectacular lighting to be viewed from a distance. As a sculptured object viewed closely the effect of lighting from below can not be considered artistic but when seen at a distance, as is usually the case, the effect as a whole is quite striking. Thus another point is worthy of consideration, namely, whether the architectural details of an exterior are to be viewed at close range or the effect is to be judged as a whole at a considerable distance.

The most stupendous application of artificial lighting to exteriors ever attempted is found in the lighting of the Panama-Pacific Exposition. Hundreds of individual effects were obtained by lighting groups of sculpture and whole building exteriors were often only a portion of a grand scheme. A noteworthy characteristic of this gigantic installation of lighting was the cooperation of the architects and engineers with the lighting specialists, the chief of whom was W. D'A. Ryan. The story of this wonderful undertaking and an analysis of the harmonious effects of light, shade, and color conceived with daring and executed with perfection, would fill a volume. The lighting at the Pan-American Exposition marked the exit of the old and misconceived idea of revealing the architectural beauty at night by outlining the buildings with incandescent electric lamps where the buildings furnished a background for thousands of glaring points of light. Many of the outlined patterns were beautiful and the whole effect was spectacular; but the architectural beauty was really obscured. The lighting of the Pan-

Fig. 97 — The beautiful Woolworth Tower.

(Courtesy of New York Edison Company.)

Fig. 98 — Light and Liberty.

Fig. 99 — At the Panama-Pacific Exposition.

ama-Pacific Exposition marks another epoch in the art and science of illumination. It was done chiefly by masked lighting diffused upon softly illuminated façades and emphasized by brightly lighted towers, individually illuminated sculptures, and many color effects. No brief description can do adequate justice to this

Fig. 100 — At the Panama-Pacific Exposition.

wonderful spectacle of light or pay due respect to the lighting genius in whose imagination it was born and through whose ability it was brought to a successful realization. The beauty of the whole exposition exterior was preserved and perhaps enhanced by concentrated effort in applying modern knowledge of the utilization of light.

In Fig. 99 is shown a night view of the Tower of Jewels. The effectiveness of the lighting is multiplied by the mirrored surfaces of the lagoons. Each view is replete with examples of light and shade effects and could be long observed and carefully studied with much profit. In Fig. 100 are shown the illuminated Italian Towers of the Court of Flowers and their images reflected from the adjacent lagoon. Space does not permit showing many of the beautiful night scenes or presenting a more extended discussion. The entire illumination effects, however, can be considered as an application on a large scale of many of the principles laid down throughout this book. It emphasizes the fact that there is a science of light and shade that must precede the art and finally go hand in hand with it.

A further discussion of lighting and architecture will be found in the last chapter.

CHAPTER X

LIGHT AND SHADE IN PAINTING

By skillfully handling light and shade in painting the artist is able to produce the illusion of three-dimensional objects upon a flat surface of two dimensions. It is left to the eye to infer the true forms of the objects represented, their nearness or remoteness, their positions with respect to each other, and their relative sizes in quite the same manner that it infers these facts in nature — chiefly by the relation of the light and shade. It is true that color is a helpful aid to the artist for by its gradation in hue and saturation the surface character of objects is revealed and the illusion of distance is obtained. Furthermore, color assists the artist in many other ways closely related to light and shade effects. While the painter enjoys certain advantages such as decision of shadow and a more completely fixed effect of light and shade in his finished product as compared with the sculptor, he is also always limited by the scanty range of contrast available from pigments. The subject of painting[1] therefore provides an interesting and fruitful field for studying the science of light and shade. Many of the points discussed in this chapter are directly applicable to stage-craft, interior decoration, and the lighting of the flat boundary walls of an interior.

In the discussion of light and shade in painting

---

[1] M. Luckiesh, London Illum. Engr., March 1914; Lighting Jour., April 1913; March 1914.

there are three distinct viewpoints, namely, the appearances of the actual objects, the process of reproducing these appearances on a flat surface in light, shade, and color, and the lighting of the finished work. The artist is in reality a link between two lightings. He attempts to preserve a certain expression of light. This expression of light is capable of thorough scientific analysis, the record however being presented in terms of measured brightnesses, hues, and saturations of colors — quite different from the artist's record. The latter is limited in accurate reproduction by the limitations of pigments which is often a disadvantage. However the painting should depart from realism to a certain extent because its object is chiefly to represent what the artist *sees* and perhaps something more, namely that gained through the remaining senses. It may be well to dwell upon the difference between that which one *sees* and the reality. The photographic camera can be made to record the detailed picture with fair accuracy but the eye only sees a small portion of a scene in true focus, the remainder being more or less out of focus. Furthermore, the fact that sensations do not instantly rise to full value or decay to zero complicates the making of a painted record of that which is looked at because the eye does not see an instantaneous pose of splashing waves or of a galloping horse unless for a certain finite period of time the objects are stationary. To paint a record of the visual impression is, therefore, extremely difficult and the difficulty increases when the artist attempts to reproduce in light, shade, and color the whole impression which is the visual experience plus the impressions gained through all of man's interpretive senses. Painting in a broad sense is therefore the expression of impressions perhaps greatly exaggerated to produce a fairer creation than that which actually exists. This analysis of the art of painting is presented in order to reveal the author's idea of what painting does or strives to do. In the consideration of the science of light and shade in painting it is necessary to confine the discussion to realism and the visual sense or to the reproduction of the appearances of objects as they are seen in true focus. Other data of interest here are presented in the chapter on Vision.

The range of contrast obtainable by means of pigments uniformly illuminated is almost infinitely small compared with the extreme ranges of contrast actually measurable in Nature. The reflection coefficients of representative substances are presented in Table I and from these it is seen that a very white substance, such as zinc oxide, is about 200 times brighter than black velvet and about 50 times brighter than ordinary black cloth under equal intensities of illumination. The 'black' pigments ordinarily found on the artist's palette reflect much more light than black velvet so that the actual range of contrast obtainable by pigments alone is often scarcely thirty to one. How insufficient these are, without the employment of illusions and the dependence upon the imagination, for depicting light and shade in Nature! The sun is millions of times brighter than the deepest shadows in the same scene. Even near sunset, the sun is thousands of times brighter than the deep shadows in the same landscape. Often the sky is hundreds of times brighter than the deepest shadow and usually a bright cloud is so much brighter than the adjacent patch of blue sky that the entire range of contrast available in pigments would be exhausted in representing these in true relative values leaving no possibility of representing the extreme range of brightness still remaining in the landscape. These are the fundamental facts regarding the limitation of light and shade effects in painting, yet many artists have been surprised on hearing these statements. Certainly every artist has experienced these difficulties many times and must be acquainted to some degree with the limitations of pigments with respect to their range in brightness contrast. Much of the data presented in Chapter VII is of interest here. For instance Tables VII and VIII illustrate the preceding point notwithstanding no very dark or bright objects appear in this particular landscape. It will be noted in Table VIII, however, that a white horizontal surface (1) was 50 times brighter than a horizontal gravel roof (9) on the sunny day and 77 times brighter than a red brick wall. If high-lights from glazed objects on a sunny day and dark cavities had been added to this table, the range of brightnesses would have been many times greater. In this connection it is of interest to describe an experiment which emphasizes the fact that ordinary black surfaces, such as black paper, cloth, or paint, reflect a considerable amount of light. If a box be lined with black velvet and a black cardboard with a hole in it be placed tightly over one end, the hole will appear very much darker than the black cardboard. In fact the latter appears surprisingly bright for a black object. (See Fig. 106.) In connection with the foregoing discussion it is helpful to consider the data presented in Chapter V on the scale of values.

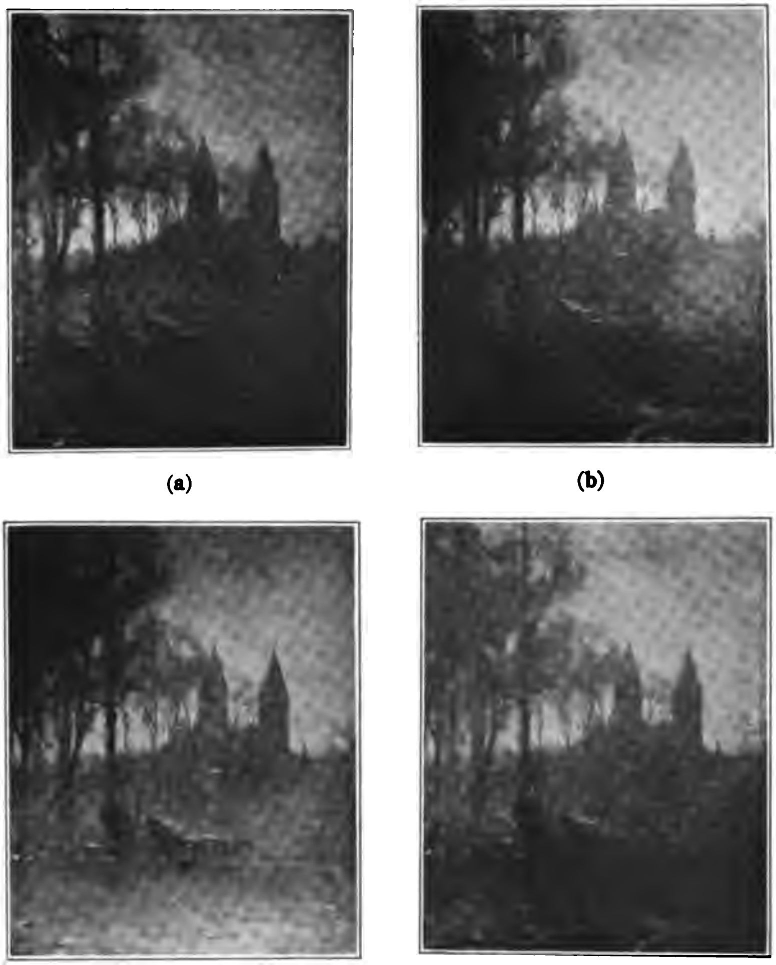
Neutral pigments, white, black, and grays, remain of the same relative brightnesses under any illuminant. This is not true of colored pigments as seen in Table

VI. The reflection coefficients or relative brightnesses of a series of fairly saturated colored pigments were determined under daylight illumination from the sky and also under the light from an ordinary vacuum tungsten lamp operating at 7.9 lumens per watt. It is seen both in the table and in the corresponding illustration referred to above that the relative brightnesses are quite different under the two illuminants. It is obvious that if a series of colored pigments were made less saturated, that is, were diluted with white or gray, their relative brightnesses would not be as greatly altered under different illuminants as when they were of high purity. Obviously if the colors were monochromatic (although none exist among pigments found in Nature) their relative brightnesses under a given illuminant would correspond to the relative amounts of the corresponding monochromatic light existing in an illuminant. An idea of the relative brightness of one of these theoretical monochromatic pigments under two different illuminants can be obtained by comparing the relative amounts of energy of the corresponding wave-length in the radiation of the two illuminants by means of the data presented in Fig. 48. It should be noted that the curves in Fig. 48 represent relative energy but not luminosity. If two curves be compared at a given wave-length the ratio of the ordinates or heights of these curves at this point represents in general either relative energy or relative luminosity. This does not hold for a comparison of the curves at different points because the luminosity is not related in any simple manner to the energy throughout any range of wave-lengths. Ordinarily no amount of energy beyond the extreme violet (about 0.4μ) or beyond the extreme red (about 0.8μ) will produce a sensation of light. The maximum luminosity of a given amount of radiant energy is produced by a wave-length corresponding to the yellow-green (about 0.55μ). These foregoing limitations of pigments and the effect of the illuminant on the relative brightnesses of colored pigments play a more important part in painting than most artists realize. In fact a full realization of their importance is not possible without an intimate acquaintance with actual measurements.

Many colored paintings have been analyzed by means of a photometer arranged to measure brightness and the change in the relative values of a painting as studied under different illuminants is very striking. On considering this effect along with the shift in the hues of the different colors it is obvious that the appearance of a painting or other vari-colored object is quite dependent upon the illuminant under which it is viewed. In order to demonstrate the magnitude of the effects of the illuminant on the relative values let us assume that a patch of sky is represented by means of the blue pigment in Table VI and an adjacent cloud by the yellow. The reflection coefficients of the two pigments for natural skylight entering a window are respectively 0.23 and 0.60. The ratio of the brightness of the yellow pigment to that of the blue pigment under illumination from the sky is 2.64. The reflection coefficients of the blue and yellow pigments for the light from the tungsten lamp used in obtaining the data presented in Table VI were respectively 0.17 and 0.65. The ratio of the brightness of the yellow pigment to that of the blue pigment under the illumination from the tungsten lamp is 3.8 or about fifty percent greater than that under skylight illumination. Thus it is seen that the illuminant influences considerably the values or skeleton of a painting or other vari-colored object. A number of paintings showed very marked changes of this character. For instance, in one case a patch of sky appeared of twice the brightness of an adjacent cumulus cloud under daylight illumination yet under the light from an ordinary incandescent electric lamp the two appeared of practically the same brightness. This brings to mind another noteworthy fact well illustrated in this actual case. The blue sky was of greater brightness than the sunlit cumulus cloud, a condition never true in Nature. In fact sunlit cumulus clouds are nearly always many times brighter than blue sky. Many such inaccurate cases have been detected by measurement although some of them are excusable owing to the limitations of pigments. It is the desire of the author that these measurements be understood as having for their object the study of the science of light and shade and the advancement of the art but not for the purpose of furnishing data to be used as a basis for the criticism of paintings. These are the facts, and science uses only facts. They are presented for the use of the artist and those engaged in the art of lighting. It appears that such data would be of extreme value to the art student.

There are many uses of light, shade, and color in the art of painting not only in imitating the appearances of natural objects but in conveying a mood or in suggesting such a condition as a glaring, uncomfortable, hot day. The artist in painting a barren desert scene often adds to the discomforting impression through the suggestion of a glaring hot sun by means of short, sharply-outlined shadows which do not fail in indicating clear noon-day sun. In order to produce the illusion of intensely illuminated colored objects these colors when represented upon the canvas should usually be less saturated than the actual colors. On the other hand in this barren desert scene the impression of a bleak, cold day is produced by eliminating sharp shadows. In fact, in this case the shadows would not be clearly outlined and would be practically absent, thus indicating a cheerless overcast day. The moods of Nature are numberless but the light, shade, and color effects can be studied with profit in order to have Nature's tricks at the tip of the brush. Many of these examples could be presented because they are always to be seen if looked for analytically. The resourceful artist must be more than a casual observer—he must be an analyst. The scientific facts must form the basis of any art but of course these must be supplemented by a sort of legerdemain in order to express, by means of pigments of great limitations, the whole impression experienced while gazing at a given scene.

The distribution of light upon a flat surface, such as a painting, considerably influences the light and shade effects and, if carefully done, can aid somewhat in overcoming the limited range of contrast available by means of pigments. The lighting expert should bear the same relation to a finished painting as the musician bears to a musical composition. It is always a safe plan to illuminate a painting uniformly by means of natural daylight or artificial daylight, thus preserving the hues and relative values painted by the artist. However, inasmuch as the artist doubtless realized to some degree at least the limitations of his pigments, any intelligent attempt to overcome the handicap imposed by pigments of limited range in contrast might be welcomed. In Fig. 101 are shown several expressions of the same painting obtained by varying the distribution of light upon its surface. In this outdoor scene the actual contrast range was several hundred to one. The greatest range of contrast on the actual painting was no more than twenty to one when the painting was uniformly illuminated. The actual sky was perhaps the brightest portion of the scene and was several hundred times brighter than the deepest shadow. If this sky area on the painting were illuminated to an intensity five times greater than the deepest shadow, it would appear 100 times brighter than the deepest shadow. Thus by properly applying an unequal distribution of light upon a painting the contrast range can be extended so as to approach somewhat toward that which is actually experienced in Nature. In Fig. 101 four different appearances of this painting due to different distributions of the incident light are presented. The effect shown in *a* was produced by means of a clear incandescent lamp placed on the left about two feet from the picture and somewhat in front of the plane upon which the painting hung. The limitations of photography prevent a very satisfactory reproduction of these effects. In *b* the effect was produced with the source two feet from the upper right-hand corner, which represents the best lighting for this painting. The effect is far superior to that produced by uniform illumination. The effect of lighting from the bottom is shown in *c*. Such a distribution of light actually decreases the contrast range considerably and is to be condemned in general. In order to overcome the annoying specular reflection of the image of a badly-placed light source from the glazing of the picture directly into the eye, the light source is sometimes placed below. This usually results



(a) (b)

(c) (d)

Fig. 101—Illustrating the effect of varying the distribution of light on a painting.

in improper light and shade distortion and actually places a greater handicap upon the artist. Inasmuch as the brightest areas of paintings are usually at the upper portions of the pictures, when local lighting units are used they should be placed above and in a proper position. In *d* the effect of a light source two feet from the upper left hand corner is represented. In general, if distribution of light is to be used in accentuating the contrast, thus counteracting the limitations of pigments in this respect to some degree, the best rule is to illuminate the high-lights to a greater intensity than the shadows. In this connection it is well to bear in mind the difference between illumination and brightness. The former deals with invisible light flux quantitatively; however, the latter depends not only upon the amount of incident light per unit of area but also upon the reflection coefficient of the given area.

The method of accentuating light and shade effects described above is perhaps the best practical scheme applicable at the present time. It is not all that can be desired by any means but is worthy of application in special cases at least. Fortunately most paintings are brightest in the upper portions so that the method is practicable in trough lighting to some degree. Obviously no advantages as just described can be obtained in galleries where paintings are lighted by means of diffusing skylights or non-localized units. In these cases it is well to consider carefully the extreme angles at which the rays strike the painting in order that annoying reflections from the glazing or glossy surface of the painting be avoided. Simple optical laws prevail here so that bad conditions are usually inexcusable and can be attributed only to ignorance or indifference on the part of those responsible in these cases. Further, light should not fall too vertically on a vertically hung picture owing to the shadows cast by the frame and by the raised portions of the pigments.

An interesting method of accentuating the range of contrast in the light and shade of a painting, although impractical for actual use, was exhibited by R. W. Wood. A photograph of a painting was taken and from this a transparent positive image was printed. This positive was placed in a projection lantern and projected upon the original painting in exact coincidence, with the result that the high-lights received light through portions of the positive that were quite transparent and the shadows received light through portions of the positive which were more or less dense. Thus the contrast was increased very much. The experiment is very edifying. Many applications of unequal distribution of light find a welcome place in other fields such as interior lighting, stage-craft, and decorative effects.

Sometimes it is of interest to place the lighting units in approximately the same position with respect to the painting as that occupied by the predominating light source in the actual scene. In some cases this will not be the correct position for accentuating the range of light and shade but the experiments are interesting. A group of photographic portraits is satisfactory for such an experiment. Usually the original lightings are sufficiently diverse so that these portraits can be placed in various positions on the wall. A wall bracket with the light shielded from the eyes answers the purpose very well. It is very interesting to group the photographs about this unit on the wall and to study the effects. A great deal of profitable study of light and shade can be applied to the ordinary things about us and it is hoped that this chapter in combination with data in other chapters will inspire study and application of the effects of light distribution on flat surfaces.

CHAPTER XI

LIGHT AND SHADE IN STAGE-CRAFT

The art of the theatre is fully realized when the text of the play, the acting, and the setting are harmoniously blended. In most plays the setting should perform no more positive service than to provide a proper frame for the piece. However, the staging of the play is always of great importance and can be made to aid in the expressiveness of the text and in its appeal to the emotions and to the intellect. Light, shade, and color effects when produced by an artist thoroughly familiar with the development of the play step by step, and its aim as a whole, can not only provide a proper frame for the piece but can go further and express something that spoken words can never fully do. In attempting to discuss this subject it is difficult to resist dwelling entirely upon the new movement in the theatre and to control enthusiasm for this movement which has revealed so many flaws in present stage-craft. The modern theatre, of which there are very few examples in existence, is the result of a recognition of the lack of harmony of the play, its setting, and lighting. The new stage-craft attempts to perfect an ideal presentation of the play.

The stage as it exists today presents many incongruous and grotesque light and shade effects. The foot-lights produce lighting effects that are abominable; the expression of the features of the actors is often grotesque, as exemplified in Fig. 60; and the distribution of light upon the stage as a whole is unnatural. Not long ago a stage setting consisted chiefly of flat canvases upon which everything possible was painted. Now the box-set interior is common in which actual furniture is used but on the flat canvases the cornices, moldings, and other projections are painted. Observation reveals the fact that these painted shadows and other light and shade effects are never in agreement with the real shadows and the distribution of light and shade produced by the stage lights. The painted perspective can never be exact, or even nearly so, excepting from only one position in the theatre. These defects have been recognized but no general attempt has been made to eliminate them. In a few theatres the footlights have been abolished and the lighting of the actors' faces has been accomplished with lights behind the proscenium arch. It is true that the foot-lights afford the easiest means for illuminating the actors but artificial light can be so easily controlled that the difficulties arising from the elimination of foot-lights can be overcome by a combination of the resources of the architect and lighting expert.

Enclosing walls are necessary in any stage setting but painted shadows can be reduced to a minimum and often eliminated entirely as is done in the new theatre settings. In the new theatre the few furnishings are always real instead of being merely painted with the many resulting objections, some of which have been noted in the foregoing discussion. The flats that are used should be of such surface character as to diffusely reflect the light and with the light sources properly placed a satisfactory distribution of light and shade can be obtained. With the same setting many moods can be expressed by merely manipulating the light and shade distribution on the various enclosing flat surfaces or draperies. This can be demonstrated very readily in any room but in Fig. 113 this point is illustrated in four sketches by Gordon Craig, a pioneer in the new movement in the theatre. These illustrate the expressive ability of light and shade distribution, for little is changed in these four illustrations excepting the values or brightnesses and their distribution. On combining with the possibilities of light and shade those of color, the stage artist controls resources of unrealized value. Such effects as silhouetting the actors against a bright ground or brightly illuminating the actors against a dark ground, a flood of light or a concentration of it represent extremes between which many possibilities lie. All these are obtained by the simple but artistic manipulation of lighting.

Many of the effects obtained in the theatre are beautiful and impressive in themselves. Even the modernists of the theatre admit this but their objection lies in the lack of harmony between play and setting and the failure of many of these ingeniously arranged and lighted settings to assist the play as an 'emotional and intellectual stimulus.' The new movement was necessarily accompanied by a development of a new stage-craft. Flats, draped curtains, and folding screens of uniform tints have been used for interior and exterior walls. The few furnishings such as moldings, cornices, mantels, steps, and furniture are real, thus appearing in true perspective and casting true shadows. In the place of the back drop-curtain a sky-dome has been used in some of the European modern theatres. This consists of a dome of a translucent or diffusely reflecting medium of such a texture that the illusion of distance is obtained without unnatural perspective.

This atmospheric background is natural and inconspicuous and, therefore, does not attract the attention from the action of the play. The effect is more in harmony with the aim of the play than the overdone naturalism obtained with the customary stage equipment. Simplicity and the artistic use of light, shade, and color in a manner which harmonizes with the play is the keynote of the new stage-craft. There is a well marked and even unfriendly disagreement between the exponents of the old and new stage-craft but certainly the old stage-craft will be benefited by the ideas that are being worked out in the new. Much of the discussion throughout this book is applicable to stage-craft so that it is deemed best and also sufficient to include in this chapter only a brief summary of the important features of light and shade which should receive attention in the theatre.

CHAPTER XII

LIGHT AND SHADE IN PHOTOGRAPHY

In photography, light and shade is of very great importance from many viewpoints. Ordinarily the photographic process fundamentally involves the action of light on silver salts, the combined action of light and chemicals used in the development of the image resulting in a reduction of silver. The reduced or metallic silver being opaque, an image in blacks, grays, and whites appears if the negative be viewed against a white surface. The amount of silver reduced depends upon the duration of the exposure and the intensity and actinicity of the rays reflected by various portions of the object photographed. The portion of an object which reflects practically no actinic rays will appear quite transparent in the developed and fixed image in the photographic emulsion. Other portions will appear various shades of gray depending upon the actinic value of the radiation which these portions of the object reflect. Thus the significance of the term 'negative' is apparent. When a photograph is made of this negative, a 'positive' picture results. Thus in ordinary photography it is the aim to produce a picture of an object or group of objects in light and shade. That true values of light and shade are seldom produced in the photographic process must be known to all photographers but the reasons are doubtless more or less obscure.

It is beyond the scope of this treatise to present a detailed account of the interesting photographic process but a few chief points will be brought out in order to make the treatment of light and shade as complete as possible. It must be understood that the 'photochemical' rays and 'visible' rays are not identical. In fact some of the rays which are very active in the ordinary photographic process are ultra-violet rays incapable of producing a sensation of light. The most active rays photographically are those of wave-lengths corresponding to nearly the extreme short-wave end of the visible spectrum, namely the violet rays at about 0.44μ. However, the rays capable of producing a maximum sensation of light are of those wave-lengths corresponding to the middle of the visible spectrum, namely the yellow-green rays at about 0.55μ. This point is illustrated diagrammatically in Fig. 102 where the curve, *B*, represents the spectral sensibility curve of an ordinary photographic plate. Although photographic plates bear a great many different names, a great majority of the plates commonly used have spectral-sensibility characteristics approximating that shown in *B*. The ordinates or vertical heights of the curve represent the actinicity or photochemical ability of equal amounts of energy of various wave-lengths. Perhaps it is well at this point to refer to the discussion of the nature of light as briefly presented in Chapter

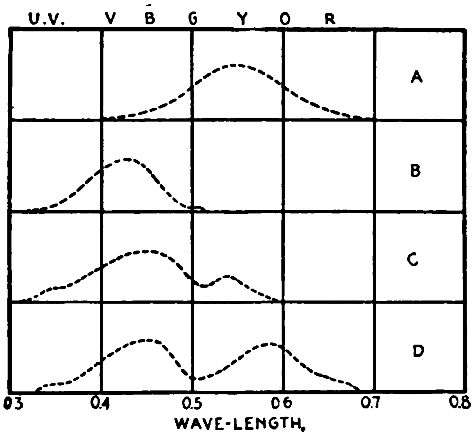


Fig. 102 — Approximate spectral sensibilities of; A, eye; B, ordinary photographic emulsion; C, orthochromatic; D, panchromatic.

II. Curve *A* represents the relative luminosity of equal amounts of energy of various wave-lengths, the eye being the recording apparatus in this case. It is quite obvious on comparing these two curves that an ordinary plate in general can not record light and shade in true values. For instance if a series of colored papers, which appeared of equal brightness to the eye but varied in hue from violet to red, were photographed, the violet and blue would appear white or light gray in the final positive print, the green a medium or dark gray, and the yellow, orange, and red would appear very dark gray or even black. It is also obvious that an object might appear quite dark to the eye as compared to a yellow surface yet the former, if it reflected the deep violet and ultra-violet rays in relatively large amounts, would appear quite a light gray in the final positive picture while the image of the yellow surface would appear quite dark. Thus it is seen that the ordinary photographic plate can not be relied upon to furnish a reproduction of light and shade on colored objects in true values. If the objects have the same kind of surfaces and the same reflecting characteristics spectrally, true values of light and shade can be obtained providing correct exposure and development are given and providing the range of brightness to be photographed does not exceed the contrast range obtainable with the plate used.

There is a general class of photographic emulsions, those called orthochromatic, whose spectral sensibility extends somewhat further into the visible spectrum as indicated diagrammatically by curve *C*. It is not unusual to find photographers who believe these emulsions ordinarily render true values of light and shade; however, this is not true although they are a marked improvement over the ordinary emulsion owing to the increased sensibility to yellow and green rays. These plates constitute only a very small percentage of the plates in common use notwithstanding their marked superiority over the ordinary plate for some work. It should be noted, however, that the great bulk of portrait photography depends upon the light and shade effects produced by lighting, the colors in the original object playing only a relatively small part, especially in the art of portraiture.

Only with the panchromatic plate, one sensitive to all visible rays as indicated in curve *D*, is it possible to record true values of light and shade in general. However, no panchromatic plates are available that will do so without the use of a carefully made color filter. Even the filters usually recommended for use fall far short in altering the spectral character of the light so that the plate may record *true* values. Usually the combination of a panchromatic plate and well-chosen filter will produce results that are satisfactory but where high accuracy is desired the filter must be carefully made for the particular plate to be used. The making of such an accurate filter is a very tedious task. In Fig. 103 is shown the spectral sensibility of a well-known panchromatic plate, *P*, compared with that of the eye, *E*. Obviously in order for a plate to record true values of light and shade in general its spectral sensibility must be identical to that of the eye. The spectral sensibility curve of a photographic emulsion can be altered somewhat by the use of sensitizers and other means but colored filters must be used finally to alter the spectral character of the light so that the rays to which the plate is too sensitive are reduced in intensity by correct amounts. Owing to a great amount of accurate work which the author desired to perfonn in representing light and shade in true values by means of the photographic plate, a filter was accurately made and has been kept properly correcting for a certain panchromatic plate. The accuracy is shown by the circles in Fig. 103, which lie close to the spectral sensibility curve of the eye. This is obtained by suppressing all of the ultra-violet rays, a great percentage of the violet and blue rays, and quite a percentage of the yellow, orange, and red rays. Thus it is seen possible only by means of a panchromatic plate and an accurate filter to record true values of light and shade. There are, however, other difficulties that must be met properly and these can be only partially overcome.

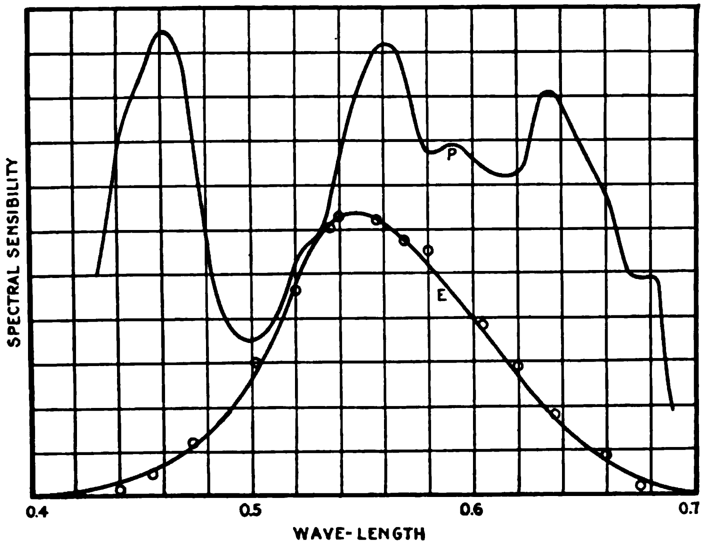


Fig. 103 — Spectral sensibility of the eye (E) and of a panchromatic photographic plate (P).

There is a limit to the range of brightness that can be recorded by a photographic emulsion although emulsions differ considerably in this respect. The limitation of emulsions is quite comparable with that of ordinary pigments employed in painting. This point is illustrated very simply by means of photographic printing papers as shown in Fig. 104. Obviously the range of contrast obtainable by means of sensitized paper depends upon the 'blackness' obtainable because 'whiteness' is fairly constant for white papers. In Fig. 104 are shown the results of measurements on eight different photographic printing papers.[1] The dashed line, *W*, represents the maximum reflecting power (maximum white) of the unexposed portions of

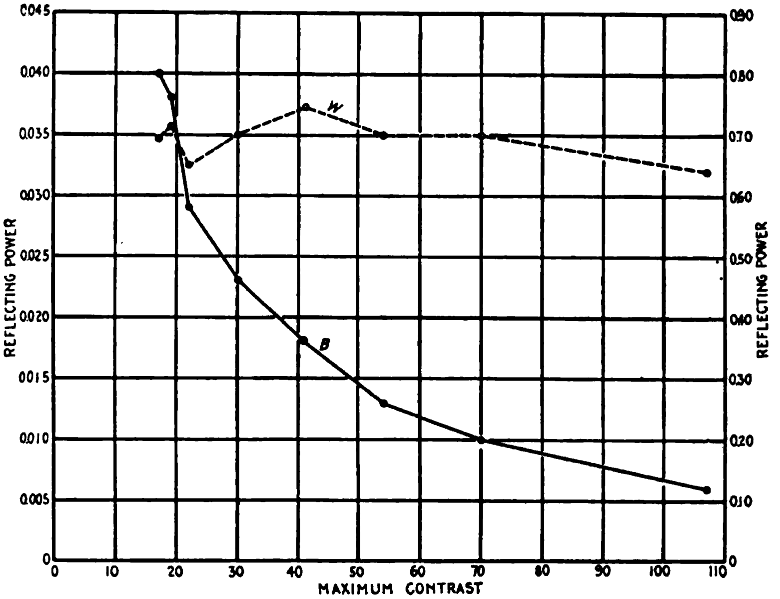


Fig. 104 — Showing the relation of the contast obtainable with photographic papers to the maximum and minimum brightness that can be recorded. Scale for 'maximum black' (curve B) on the left; scale for 'maximum white' (curve W) on the right.

---

[1] Trans. I. E. S., X, 1915, p. 389.

the papers. The other curve, *B*, shows the minimum reflecting power (maximum black) obtainable in each case. These values are plotted respectively on the right and left. Along the bottom are shown the maximum gradation or range of contrast obtainable as related to the 'maximum black' and 'maximum white.' It is seen that the maximum contrast is available with those papers for which the totally reduced silver produces the darkest gray or 'black.' The contrast available obviously does not depend upon the 'whiteness' because this is practically the same for the eight papers. Photographic transparencies such as plates and films can be investigated in the same manner although in these cases transparency is the factor considered.

Another factor upon which the recording of values of light and shade depends is the exposure. It has been fairly well established that the relation between photographic density and exposure (or brightness or actinicity) is in general similar to that shown in Fig. 105. The region of correct exposure is the straight portion of the curve. The density of the deposited silver is arrived at as follows:

$$\text{Transparency} = T = \frac{\text{light transmitted}}{\text{light incident}}$$

$$\text{Opacity} = O = \frac{1}{T}$$

$$\text{Density} = D = \log O = \log \frac{1}{T}$$

The plate is measured for its transparency at any given part and the logarithm of the reciprocal of this transmission coefficient is called the density. Plates differ very widely in their ability to record ranges of brightness; that is, the slope of the straight portion of the density-exposure curves corresponding to that shown in Fig. 105 varies with different kinds of plates. In Fig. 105 the ordinates represent density and the abscissæ can represent, in general, actinicity, exposure, or brightness of the objects if they have the same spectral reflecting characteristics. The values have been plotted on a logarithmic scale so that relative distances along the horizontal axis represent the logarithms of actinicity or exposure. The slope of the straight line portion of the curve is influenced by other factors such as development. The range of contrast that can be recorded on photographic plates varies from a low value to as high as 250 to 1 or slightly higher. However, the range that can be actually reproduced in practise when the positive is made on sensitized paper is generally very

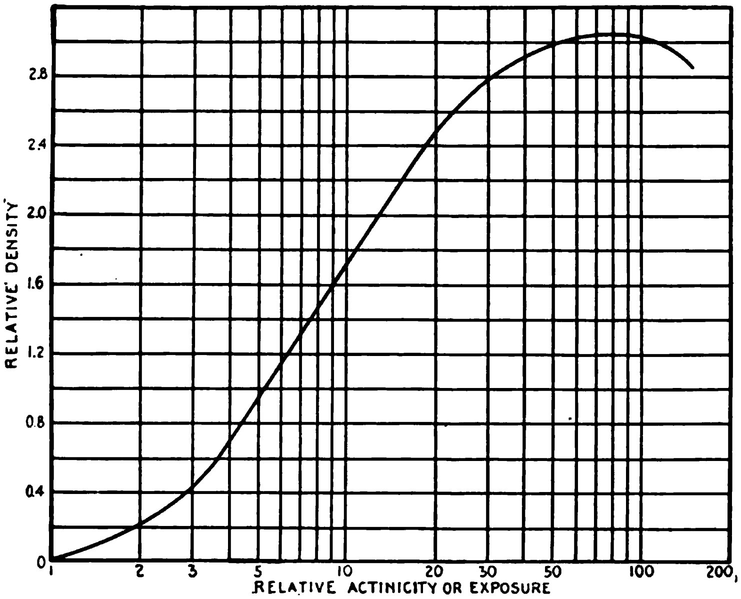


Fig. 105 — Showing the relation of photographic action and actinicity or exposure.

low, usually under 30 to 1. The limitation of the photographic process is thus seen to be in general about the same as that of pigments. This is not surprising because in a sense the reduced silver is merely a neutral pigment.

Anyone desiring to photograph considerable ranges of brightness should select photographic plates, films, or paper with care. Data on the gradations obtainable with various plates often can be obtained from the manufacturers of such material; however, it is a simple matter to test plates at hand by photographing a series of brightnesses such as the value scale described in Table IV. An interesting experiment, which not only illustrates the limitations of the photographic process but also shows that objects ordinarily considered black are really quite bright when compared with an object which is practically black, is performed as follows. In an oblong piece of so-called black cardboard having a matte surface, two holes are cut. One half of this cardboard is placed over the end of a box which is lined with black velvet, the hole in the cardboard being much smaller than the cross-section of the box. The cardboard should be so placed that one of the holes is in the center of the open end of the box. The hole in the other half of the cardboard which projects from the box is covered with black velvet glued on the back side of the cardboard. The procedure will be understood readily on referring to Fig. 106 which is a reproduction of a photograph of the 'black' cardboard containing one *black* hole, *H*, and one hole covered with 'black' velvet, *V*. The limited range of the two photographic processes involved in obtaining the original, namely, the negative which was obtained on a plate of more than ordinary gradation and the positive which was printed on sensitized paper exhibiting a fair range of gradation, is well shown. In the final print the image of the black hole was as black as could be obtained on the paper, the 'black' velvet square appeared a dark gray and the 'black' cardboard with matte surface appeared white. Thus it is seen that the range of brightness represented by the 'black' cardboard and the really black hole was as great as could be reproduced photographically. As already stated this experiment not only illustrates the difference in brightness between a real black hole and objects which are usually considered black but also the limitations of the photographic process.

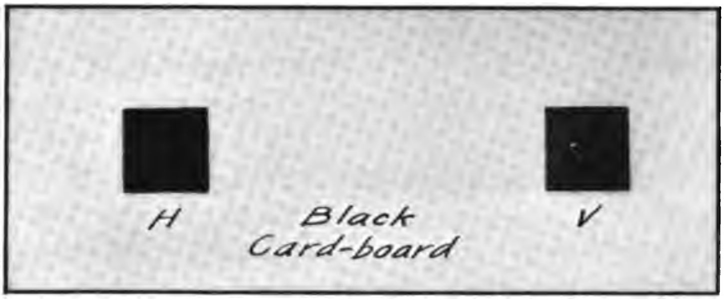


Fig. 106 — Showing the different degrees of 'blackness' of 'black' cardboard, 'black' velvet, and a *black* hole. This also illustrates the limitation of the photographic process in recording brightness.

The development influences the slope and extent of the straight portion of the curve shown in Fig. 105, thus altering the relation of the values of light and shade. The thickness of the emulsion affects the range of gradation obtainable, in general the thicker emulsions yielding the larger ranges. Obviously, with a plate having a small range of gradation, the detail in shadows will be obtained usually at the expense of the detail in the high-lights and vice versa. There are many other factors in the photographic process which might be discussed with profit but the foregoing points are of chief importance in the science of light and shade as treated in this book. It should be borne in mind that in reproducing most of the illustrations in this book several photographic processes have been involved and in many cases the limitations as brought out in the foregoing have robbed many of the illustrations of some of their value.

It is natural that in a general treatment of a subject many other chapters contain data directly connected to the phase of the subject under discussion. This is especially true in this present case. The entire book contains material of interest to those especially interested in the art of photography, so that much will be omitted in this discussion. However, inasmuch as Nature is often photographed, one point will be discussed that has not been touched upon in Chapter VII. It is well known that various illuminants differ in actinicity or actinic value per unit of radiant energy. Inasmuch as the photographer uses the eye as his measuring instrument, a more practical unit of actinicity, although perhaps not as desirable scientifically, is the actinic value per unit of light or brightness. The photographer, very wisely, does not often use different illuminants at the same time. This is because in general the visual appearances of the brightnesses due to the different illuminants will not bear the same relation in the photographic results. This is obvious when it is considered that the actinic value per unit of light differs with various illuminants. There is one case where the photographer can not escape contending with two different illuminants, namely, outdoors on a clear day. It has been found that skylight is practically twice as actinic per unit of light as direct sunlight for ordinary plates.

This is due to the fact that there are greater percentages of ultra-violet, violet, and blue rays in the radiation from the sky than in direct sunlight. This results in the shadows outdoors on a clear day being more actinic per unit of brightness than the high-lights. In many cases this tends to overcome the difficulties or limitations due to a scanty range of gradation obtainable with photographic emulsions. Nevertheless this point must be considered in outdoor photography when true values of light and shade are desired. In Fig. 53 the relative luminous intensities of light from the sky and from the direct sun are presented. In Fig. 107 the relative photographic effect of skylight and direct sunlight received on a horizontal surface on a clear day are presented for an entire day. These values are not for equal luminous intensities but are given for the total light without any attempt at equalizing the intensities. Obviously the results would differ on various

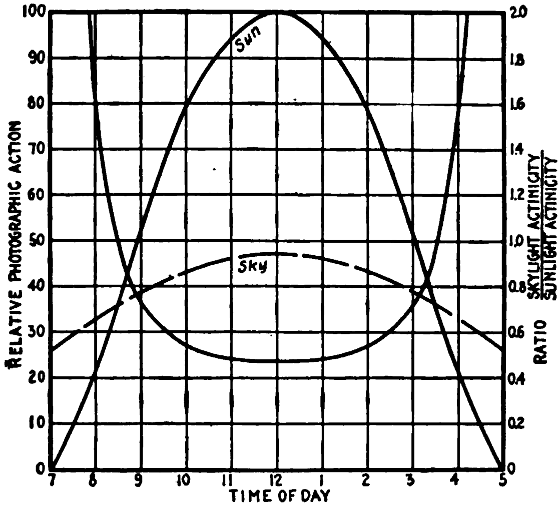


Fig. 107 — Relative actinicities of sunlight and skylight.

days but in this case it is seen that for a considerable portion of the day, skylight was more effective photographically than direct sunlight, notwithstanding the illumination intensity due to the latter was greater than the former throughout a portion of this time. The third curve whose scale is on the right side gives the ratio of the photographic value of the total skylight received on a horizontal surface to that of the total direct sunlight on the same surface.

Much that has been presented in the foregoing is designed to prepare the photographer to reproduce light and shade as satisfactorily as possible whether the light and shade be on flat surfaces or three-dimensional objects, or whether they be vari-colored, monochromes, or neutral-tinted surfaces. Much could be presented pertaining to the lighting of three-dimensional objects but a great deal has been incorporated in previous chapters, especially in Chapters VIII and IX. The latter will not be repeated excepting briefly as pertaining especially to the subject of portraiture. The study of the importance of lighting a subject in order to obtain proper effects of light and shade, is fully as important as posing the subject. Light should be used to model the features properly. It is the lighting that models the objects and imparts variety and character to the composition; nevertheless lighting is very much neglected by many photographers notwithstanding its great importance. The pose and the lighting are so closely allied that much profit can be gained by studying the masterpieces of art. It is not the object here to attempt to discuss the art of light and shade but rather the science. This has been the aim throughout this entire treatise. Doubtless a child or woman should generally be brightly lighted with soft, gradated shadows while the portrait of a man should show more marked contrasts of light and shade. It is the object in the following discussion, as in some of the previous chapters, to present the factors which are of importance in obtaining desired lighting effects and to show the extreme simplicity of the procedure. Many names have been applied to various kinds of lighting employed by the photographer. Obviously in these many variations and combinations of them, lies the opportunity for individuality. For the present purpose lighting in portraiture might be divided into two classes. In one, diffused light is distributed in masses, the entire subject being placed in the light. The masses of high-lights should be counteracted by sufficient shadow in order to give solidity to the composition and to avoid the monotony of flatness. The other mode of lighting is that practised by the great master of light and shade. Rembrandt lighted his subjects to produce bold shadows which gave force to his work. He used strongly directed light which resulted in deep shadows but the secondary high-lights received light by reflection from the adjacent intense high-lights. In other words his directed light produced intense high-lights from which by reflection other surfaces appeared in semi-shadow, the whole melting into darkness. Thus in the two broad classes of portrait lighting, highly diffused light from a source subtending a large solid angle, and highly directed light from a relatively small source respectively predominate. In the first class the large bright areas dominate; in the second class strong high-lights and the great masses of shadow dominate in producing the effect.

In the lighting of a subject the photographer must consider and manipulate the same fundamental factors as the sculptor. He must bear in mind that his *lighting* is modeling the form by light and shade which, when reproduced photographically, must be depended upon to produce the illusion of relief. It is not necessary to explain to the photographer that lighting, if done improperly, will alter the beauty of the model, give hardness where softness is desired, exaggerate the defects of features, and render harm in many other ways. However, it appears of value to explain the simple fundamental factors involved in lighting three-dimensional objects. The writings on studio-lighting that have come under the author's observation, while perhaps more or less successful in describing various arbitrary or specific conditions, ordinarily do not treat the fundamentals.

It is sufficient in this analysis to consider chiefly the formation of shadows; the high-lights will almost take care of themselves as to character because they comprise what is left after the shadows have been satisfactorily produced. The general direction of the shadows depends upon the position of the dominating light source with respect to the subject. When this source is of large area and not uniformly bright, simple shadow experiments with a pencil or other object will analyze the condition satisfactorily to reveal the direction of the predominant light. There is a more or less vague rule, which might be called 'forty-five-degree lighting,' practised somewhat by many photographers perhaps unconsciously to a great degree. This rule possibly owes its origin to Leonardo da Vinci, who enunciated the theorem that the length of the shadow of an object should be equal to the height of the object. Obviously this rule is too empirical to be followed closely by those striving for individualism in portraiture, nevertheless it doubtless has been the starting point very often for the production of artistic pictures.

The next factor of importance is the solid angle subtended by the dominating light source at the shadow-producing object. This determines the character of the edge of the shadow. When the light source subtends a small solid angle the edge of the shadow will be sharp; but when it subtends a large solid angle the modulation from light to shadow will be gradual, thus aiding in the production of the characteristic of softness. Obviously the shape of the shadow-producing edge is of more importance with extended sources; for instance, the shadow cast by a rounded edge will show a more gradual modulation from light to darkness than the shadow cast by a sharp edge. It is also apparent that this difference will be less marked in the case of the light source which subtends a small solid angle. For examples of the foregoing the reader is referred to many illustrations throughout the book, especially those in Chapters III and IV. The fact that the character of the edge of the shadow depends upon the solid angle subtended by the light source and not upon the actual size of the light source is shown diagrammatically in Fig. 108. For simplicity a vertical skylight of diffusing glass is shown at *ab* and it is assumed to be of uniform brightness. The dimension perpendicular to the paper is assumed to be equal to that shown in the diagram and the shadow-producing object is considered to be at *O*. It is quite apparent that a uniformly bright source of dimensions equal to *cd* (both parallel and perpendicular to the plane of the page) will produce a shadow identical to that produced by a light source of the dimension *ab* and further away because light-rays travel in straight lines. In both cases the solid angles subtended by the light source at the point, *O*, are equal. The same is true if the two dimensions of the light source be reduced to *cf*. Thus it is possible to reduce the size of the light source and to place the subject nearer to it and obtain exactly the same results as in the original case. Another interesting fact is that approximately the same intensity of illumination at the point, *O*, will result in all three cases if the brightness of the light source (the diffusing medium) be the same in the three cases. The great advantage of portable artificial illuminants is seen in this diagram. For instance, a small artificial skylight can be used with equal satisfaction to that of a large skylight and often with better success than a common daylighted skylight because the brightness of the smaller artificial skylight can be considerably greater without annoying glare to the subject. Of course where the studio must be equipped for photographing groups a larger artificial skylight is neces-

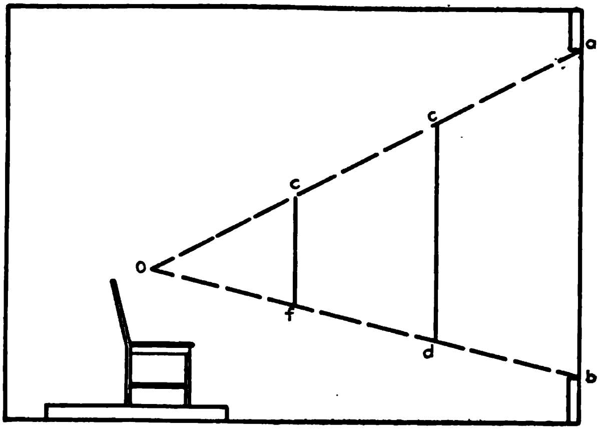


Fig. 108 — Illustrating that the shadow-producing effect at O depends upon the solid angle subtended by the light source at the point, O.

sary. However, this problem can be solved successfully in the case of the smaller artificial skylight by increasing the dimension perpendicular to the page in Fig. 108. Many portrait photographers have not fully appreciated the great advantages of modern, compact, portable, artificial illuminants especially designed for photographic purposes. Control of the factors which affect the light and shade is unlimited in the case of satisfactory artificial illuminants but only to a relatively small degree in the case of natural light.

The third chief factor involves the brightnesses or reflection coefficients of the surroundings. This factor determines the relative brightness of the shadows because these are illuminated by scattered or reflected light. In the case of sculpture exhibits and many other lightings the walls and ceiling must be depended upon to furnish the diffused or scattered light for illuminating the shadows. The boldness of the expression obviously increases as the brightness of the shadows decreases, as the shadows increase in area, and as the shadow-edges become more sharply defined. The photographer usually obtains the scattered or reflected light for the shadows by means of portable screens. He is therefore quite familiar with the importance of the scattered light and in the manipulation of the portable screens. In the foregoing the three chief factors in light and shade production are simply analyzed and illustrated. From an intelligent manipulation of these, artistic pictures are bound to result.

As already stated it is not the intention to discuss the artistic side of light and shade in photography chiefly because the object of this book is to present the science of light and shade. It is safe to deal with the latter subject because one deals only with facts that are indisputable. On entering the artistic realm one deals with an indeterminate problem because conclusions are largely matters of taste and attainments are quite individualistic. However, the author can not refrain from adding a few comments which are largely intermingled with the art of light and shade. In beginning the production of an artistic light and shade effect in portraiture the subject must first be posed. Inasmuch as the figure composition and the lighting are quite allied in the final light and shade effect, they must be imagined as a whole while each is being more or less separately arranged. The pose must be studied with definite lightings in mind and a fairly definite idea of the figure composition should be decided upon early. The figure is enhanced pictorially with its possibilities in light and shade clearly understood. Contrasts are obviously essential but the degree of contrast depends upon the subject. Besides this there is another factor which might be called 'tone.' This, in photography, is largely a matter of selecting the plate and properly timing the exposure and is therefore not of direct importance from the chief viewpoint of the author. However, it is well to divide this factor in the imagination into several general values; perhaps three will suffice, namely, the great middle tone, one above, and one below. In exemplifying this factor let us use a musical analogy. The musician may render a motif pianissimo or fortissimo but the music remains unaltered. A painter may choose a low or high key. Israel, the famous Dutch painter, stated the matter something like this, 'I never think of this point but let the sentiment direct me.'

It is not the intention to discuss the subject of artistic lighting extensively but it appears of interest to direct attention to the great possibilities in portraiture obtainable with the very adaptable artificial photographic units that have been perfected recently. The extreme portability of some of these units, especially the photographic tungsten lamps, makes it possible to depart from the limited possibilities of daylight or the clumsy artificial lighting units and obtain artistic effects in any studio which were rarely attempted until recently. That this brief mention of the new possibilities will be helpful to photographers seems evident from the lack of acquaintance on the part of many of them with the possibilities in artificial lighting at the present time. Recently a photographer, who was demonstrating his methods before a large audience of photographers, stated that he lighted his subjects without much study of the lighting but trusted to the manipulation of the development and printing to obtain satisfactory results. From his methods of lighting it was evident that he knew very little about obtaining artistic effects in light and shade. No word of protest from any photographer present was recorded against this statement. Many photographers have seen the advantage of the extremely portable and adaptable new artificial lighting units although a great number doubtless have not yet realized that daylighted studios can be greatly improved upon and eliminated entirely by the use of the most modern artificial lighting units that can be adapted to any condition.

A few examples are presented, not from the artistic standpoint but to illustrate the extreme possibilities with as few as two small units such as photographic tungsten lamps. Such a lighting as shown in Fig. 109 is now possible with artificial lighting equipment much less expensive than the ordinary skylight. Nearly all

Fig. 109 — Illustrating the possibilities of a readily portable photographic lighting unit.

of the numberless effects that can be recorded by photographic emulsions can be obtained with as few as two lighting units. In Fig. 110 are shown two very different lightings of nearly the same pose. High-lights such as these can not be obtained with the same ease

(a)

(b)

Fig. 110—Light and shade effects readily obtained by means of adaptible artificial lighting units.

(a)

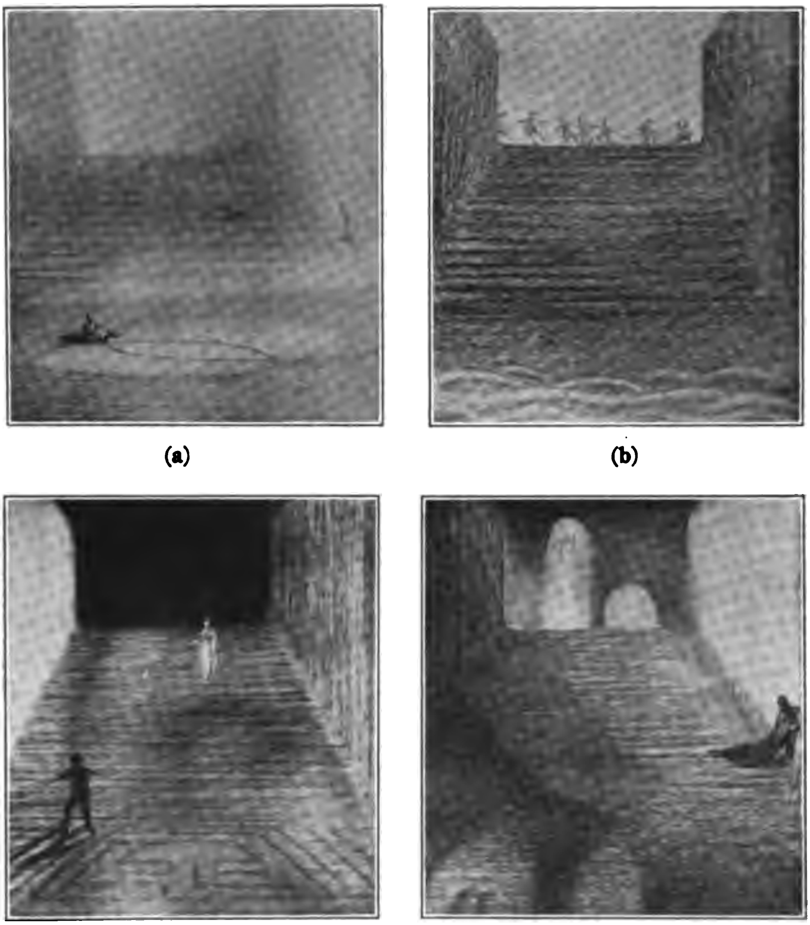
(b)

Fig. 111 — Effects easily obtained by artificial lighting.

(a) (b)

Fig. 112 — Effects readily obtained by artificial lighting.

in the daylighted studio unless under exceptionally favorable conditions. These exposures were extremely short for indoor portraiture and represent merely average results that can be obtained very simply and with an inexpensive equipment. In Fig. 111 two extreme effects are shown as obtained with the same equip-



(a) (b)

(c) (d)

Fig. 113 — Illustrating the influence of the distribution of light and shade upon the mood of a stage setting. (After Gordon Craig in his "Toward a New Theatre.")

ment, namely two portable photographic tungsten lamps. In Fig. 112 are shown two quite different effects of light and shade obtained with the same two units quickly altered in position. These are sufficient to demonstrate the possibilities of modern artificial lighting units which are extremely portable and to show that such units open new artistic fields to the photographer. It is perhaps true that many of the effects obtained by means of these artificial units can be obtained in a daylighted studio elaborately equipped with curtains and screens; however, the difficulties are usually much greater in the latter case and the results are not always as certain. The effectiveness of definite and artistic lighting is well demonstrated in moving pictures. In this field the intelligent use of light for obtaining the proper expression is beginning to receive considerable attention by the best moving picture directors. This fact is demonstrated in any moving-picture theatre. Thus, without attempting to discuss the artistic side of the subject which is considered to belong to the individual photographer, an attempt has been made to treat the scientific foundation of the photographic art which photographers must share alike among themselves. The aim here has been the same as in other chapters, namely to bring forth the importance of the science of light and shade which must supply the foundation of the art.

CHAPTER XIII

LIGHT AND SHADE IN VISION

Objects are visible owing to differences in light, shade, and color. In general the variation in brightness, that is, the distribution of light and shade, is more important in revealing the forms of objects than variations in hue. The distribution of light and shade forms the skeleton of a scene and the hues the drapery. Color, however, plays an interesting part in the appearances of objects, but this subject has been treated extensively in a previous book on 'Color and Its Applications.' Furthermore, the object of the present treatise is confined to the science of light and shade, therefore color has been treated only in those cases where it is of importance in influencing light and shade. Many of these cases were discussed in Chapters VI and IX. For many reasons vision is studied from two chief viewpoints, namely the distinction of very fine detail and the perception of brightness differences on objects of relatively large size as compared to fine details. The first is called visual acuity and the second merely the minimum perceptible brightness differences or brightness sensibility. In many cases seeing involves only one or the other although both are more or less intermingled in ordinary vision. Visual acuity is not exercised in general as much as the perception of brightness differences of surfaces relatively much larger in size. For this reason the former will be briefly discussed and passed by.

Acuteness of vision or visual acuity is usually measured in terms of the angle subtended at the eye by fine detail such as lines, small circles, letters, etc. Usually these are viewed against a white background although very interesting investigations have been carried out with colored backgrounds. In the latter studies even spectral colors have been used as fields against which the test-objects have been observed. In Fig. 114 the upper curve, *B*, shows the relation of visual acuity to the brightness of the white background under an extreme range of illumination. Different methods and test-objects yield different absolute results but the relation between visual acuity and brightness of the background is in general the same. It is seen when the brightness of the background is low, visual acuity increases very rapidly with increas-

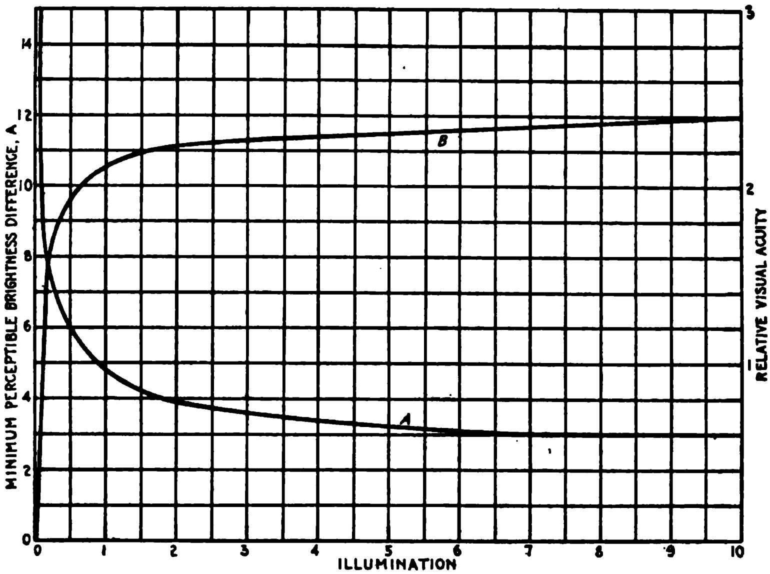


Fig. 114 — Variation of brightness sensibility and visual acuity with brightness (illumination of a white surface in foot-candles as indicated). Scale on left is per cent of total brightness.

ing brightness of the background. After the brightness of the background reaches a certain value, for example when the illumination of a white surface reaches an intensity of one foot-candle, visual acuity increases only very slowly with increasing brightness of the background. For this reason acuteness of vision is not greatly different for considerable ranges of illumination after the critical point is passed. In fact the relation for ordinary intensities of illumination might be expressed thus

$$\text{Visual acuity} = K \log I.$$

In other words, after the brightness of the background has reached a certain value, visual acuity is proportional to the logarithm of the illumination intensity, K being a constant. Experimental results indicate that this law is fulfilled approximately for the lower range of illumination although the value of the constant, K, is different. The results with colored backgrounds are of interest but not definite excepting when pure monochromatic spectral colors are used. It has been found that visual acuity is better in monochromatic light than in light of extended spectral character of practically the same hue, and is better in monochromatic yellow light than in monochromatic light of any other hue. Of course, equal brightnesses of the colored background are assumed in the foregoing comparisons.

Visual acuity is exercised in a relatively small part of seeing so that the minimum perceptible brightness difference or brightness sensibility is relatively more important in the science of light and shade. Obviously vision or the perception of differences in brightness is essential in every phase of the subject treated in this book so that a discussion of vision is quite apropos. What is perceived by the eye depends as much upon the eye or the processes of vision as upon what is looked at. Most of this book has been devoted to the appearances of objects chiefly in regard to light and shade effects. It has been shown that the appearances of objects are quite under control by intelligently manipulating the factors which affect the light and shade distribution. However, the ability of the eyes to see is not under control; that is, the processes of vision involving the physiological and psychological phenomena are established and are obviously unalterable. The perception of brightness difference is influenced by the intensity and color of the illumination, by the state and rate of the adaptation of the retina, by the distribution of brightness in the visual field, and other factors. A complete treatment of present knowledge pertaining to these factors is beyond the scope of this book but the chief points will be discussed because they are of more or less importance in dealing with the subject of light and shade.

The minimum perceptible brightness difference as related to the absolute brightness which is viewed, that is, to the intensity of the illumination of a white surface, differs considerably depending upon the method employed. Photometric sensibility with refined methods is within a small fraction of one per cent when the mean is taken of a large number of observations made by balancing a photometer field. However, if the photometer field is unbalanced more and more until the brightness difference between the two parts of the field is just perceptible, the minimum perceptible difference ranges from 1.5 to several per cent when the brightness corresponds to that of a white surface illuminated to an intensity of one foot-candle or more. In Fig. 114 the lower curve, *A*, represents data obtained in this manner. It is seen that at low intensities of illumination of the white surface the minimum perceptible brightness difference becomes quite large. Obviously at the threshold of vision this value becomes unity. In Fig. 115 the data of A. Koenig, who pioneered in the study of vision, are plotted throughout a wide range of illuminations on a white surface. This curve is an extension of that just referred to in Fig. 114, the relative illumination (or brightness) in this case having been plotted on a logarithmic scale. The maximum brightness sensibility or the minimum perceptible brightness difference is seen to be about 1.6 per cent. This minimum value or the maximum brightness sensibility of the retina is obtained in general under ordinary com-

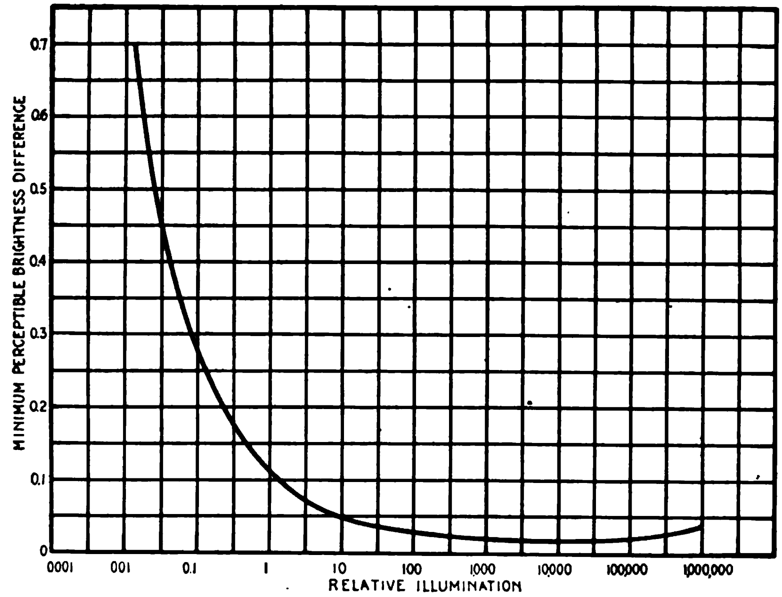


Fig. 115 — Koenig's data on brightness sensibility.

fortable natural or artificial lighting conditions. It is seen from the foregoing data that surfaces differing only a few per cent in brightness are readily distinguished from each other when the intensity of illumination is of the order of magnitude ranging from ordinary lighting intensities in interiors to comfortable conditions of natural lighting outdoors. This range is from one to as high as 10,000 foot-candles. In ordinary moonlight, outdoor objects must differ in brightness by many per cent before they can be distinguished separately, which is also true in very uncomfortable or glaring lighting conditions. However, there are other conditions which affect the brightness sensibility of the retina so that the foregoing statements are incomplete.

The eye functions satisfactorily over an enormous range as compared with any instrument developed by mankind. It tolerates absolute brightnesses differing from each other by many millions to one. For instance, it is possible to read for a brief period with fair comfort outdoors under direct noon sunlight and indoors under low intensities of artificial light, this range of intensity being represented by more than ten thousand to one. The conditions under which the eyes are used ordinarily may be divided into four classes: (1) unobstructed daylight outdoors, (2) daylighted interiors, (3) artificial-lighted interiors, (4) outdoors at night. In Table IX approximate averages are found as presented by Dr. P. G. Nutting.[1] The numbers in the first column refer to the general conditions described above. In the second column are presented the approximate mean brightnesses encountered under the four conditions, the brightnesses being given in terms

---

[1] Trans. I. E. S., X. 1915, p. 996.

TABLE IX

The Sensibility of the Eye under Different General Conditions under which the Eyes are used

Class	Approximate mean brightness	Minimum perceptible brightness difference	Threshold brightness
1	1000. millilambert	0.0175	0.35 millilambert
2	10. "	0.030	0.017 "
3	0.1 "	0.123	0.0014 "
4	0.001 "	0.79	0.00011 "

of the millilambert which can be readily transformed into other units as shown in Chapter V. For convenience these brightness levels are evaluated so as to be related to each other by multiples of 100. Fortunately the values represent, sufficiently closely for practical purposes, the rough averages of brightness under the various conditions. In the third column is presented the brightness sensibility of the retina under each general condition. The brightness difference just perceptible under the conditions obtaining in an open space outdoors on a clear day (class 1) is seen to be 1.75 per cent of the whole; that is, surfaces differing in brightness by this amount are just perceptibly different to the eye in brightness. In the fourth column the threshold brightnesses are presented. For instance, for an eye adapted to a brightness level corresponding to a mean condition outdoors in the daytime, the absolute brightness just perceptible in an immediately darkened enclosure is 0.35 millilambert. These values are only general and vary considerably depending upon the distribution of brightness in the visual field, the adaptation of the retina, and to some extent upon other factors. Dr. P. W. Cobb has shown that the brightness sensibility as studied by means of a small photometric field is greatest when the surrounding field is of the same brightness as that of the photometric test field.

It is common experience that it is difficult to see for a few moments after entering a brightly lighted room from a dark room or vice versa. This is due to the fact that the visual process requires time to become adapted to different mean brightness levels. The pupil, by varying in size, protects the eye to a considerable degree from the annoyance, discomfort, or depressed sensibility accompanying a sudden change from one mean brightness level to another considerably different. The iris does not operate instantaneously and the retina requires time to become adapted depending upon the magnitude of the difference between the two brightness levels and also upon the period of time to which it was exposed previously to the first condition. Another example of actual adaptation, which is complicated by the fact that light sensations require time for growth and decay, is experienced on observing a flickering brightness. The frequency at which flicker disappears depends upon various factors such as the brightnesses which are alternated, the wave-form of flicker, and the color. This critical frequency is less for the smaller brightnesses. Another phenomenon which is somewhat related to the foregoing but usually considered as retinal fatigue is that of after-images. After fixating the eyes upon a bright surface if they be suddenly shifted to a darker surface, a bright after-image is visible which soon decreases in brightness until it is darker than the surroundings. The former is called a positive after-image and the latter a negative after-image. If a dark object be viewed against a bright ground, a hazy bright boundary is seen around the edge of the dark object. This is often due to the involuntary slight shifting of the eyes and a resultant spread of the after-image beyond the boundaries of the dark object. This effect of a bright hazy boundary may be due in some cases to the phenomenon known as induction which is evident on viewing two surfaces contrasting in brightness. The dark and bright edges which touch each other often appear by contrast, darker and brighter respectively than the remainder of the respective surfaces. Another phenomenon often noted is called irradiation. A bright object such as the crescent of the new moon appears larger than the dark portion. This experiment can be readily performed with an incandescent lamp filament the brightness of which is controlled by means of a rheostat or neutral tint screens or with flat white and black objects of identical size placed respectively upon black and white backgrounds.

The effect of retinal adaptation upon brightness sensibility is not difficult to study although for thorough work many factors must be considered. The eye is merely adapted to a certain brightness and then is suddenly called upon to distinguish a certain brightness difference. When the eye is subjected to a bright light for a short time the sensibility falls very rapidly at first, then more slowly. If again exposed to darkness the sensibility recovers somewhat more slowly. Dr. P. G. Nutting[1] has presented the data shown in Table X for a brightness of 25 millilamberts, a brightness quite blinding to an eye adapted to darkness, yet about one fiftieth as bright as an average blue sky. Brightness sensibility is inversely as the minimum perceptible brightness difference.

---

[1] Trans. I. E. S., X. 1915, p. 996; Nat. Com. Gas. Assn., 1915.

TABLE X

Brightness Sensibility as affected by Retinal Adaptation

Time	Sensibility decrease	Sensibility increase
1 sec.	2.1 times	1.6 times
2 "	4.2 "	2.6 "
5 "	16.2 "	7.6 "
10 "	58. "	14.4 "
600 "	120. "	20.9 "

In order to interpret the data the following example is given. If the eye be suddenly exposed to a field whose brightness is 25 millilamberts, its sensibility after five seconds will have dropped to about one sixteenth of its dark-adapted sensibility; after ten seconds' subsequent exposure to darkness it will not have wholly recovered its previous sensibility when adapted completely to darkness. Many other data could be presented bearing upon various phases of the subject but the object is only to show in a general manner how the eye's ability to record differences in brightness is affected by various conditions.

Extreme contrasts in the visual field are now recognized as decreasing the sensibility of the retina and resulting in eye fatigue. In order to illustrate the tremendous contrast ranges[1] the eye is obliged to tolerate, assume a white diffusely reflecting sphere to be resting upon a black paper. In ordinary interiors the average amount of scattered light reaching the shadows of objects is roughly about 5 per cent. The reflection coefficient of the black paper is assumed to be about 4 per cent and that of the sphere 80 per cent. The brightest spot on the sphere is about 400 times brighter

---

[1] P. W. Cobb, Lighting Journal, April, 1913.

than the shadow cast on the black paper. If a gas flame illuminates the top of the sphere to an intensity of 2 foot-candles, the ratio of the brightness of the source to that of the brightest spot on the sphere is about 630 but the ratio of the brightness of the source to that of the shadow of the sphere on the black surface is more than 250,000. If the light source is a frosted tungsten lamp the two ratios are respectively about 1500 and 6,000,000 and if the light source is a clear vacuum tungsten lamp they are respectively about 250,000 and 100,000,000. If the modern gas-filled tungsten lamps or the arc lamps had been used in the computations the range of brightness which the eye must observe and tolerate would have been many times greater and for a source of the brightness of the sun the figures would have been incomprehensible. The foregoing conditions which have been computed are commonly experienced in interiors and it is seen from Chapters X and XII how extremely limited are pigments and the photographic process for recording the extreme brightness range perceptible by the eye. The whitest pigment is no more than two hundred times brighter than the blackest velvet and not more than thirty times brighter than the blackest commercial pigment under equal intensities of illumination. A photographic plate that shows a range of gradation of 250 to 1 represents practically the greatest range that can be realized photographically. When combining with this photographic process a second more limited process, namely that of printing a positive upon printing paper, the ability of the two ordinarily combined photographic processes is seen to be about the same as commercial pigments. The wonderful range of the eye in recording brightness differences is evident on comparing its ability to record brightnesses over a range of many million with the means man has provided for fixing effects of light and shade.

In closing this brief discussion of the perception of light and shade, practical examples may be of interest. Let us first assume a single light source outdoors placed high on a street-lighting standard. If two surfaces of identical reflecting characteristics are placed one foot apart and parallel to each other so that their respective distances from the light source differ by one foot, it is obvious that their brightnesses will differ. These brightnesses will be proportional to the reciprocals of the squares of the respective distances of the surfaces from the light source. The brightness differences are given in fractions of the whole in curve *A*, Fig. 116, for mean distances as great as 200 feet from the light source. When the mean of the distances of the two parallel surfaces one foot apart is 20 feet, the brightness difference is about 9 per cent. At 100 feet the brightness difference is about 2 per cent and at 200 feet is about one per cent. Under the best experimental conditions when the eyes are adapted to this level of illumination, the minimum perceptible brightness difference is at least several per cent. Under the actual conditions of variable retinal adaptation and distracting causes, the eyes can not easily distinguish brightnesses that do not differ by perhaps two per cent or more. If these two surfaces considered above were steps one foot apart and if in going down the steps the light source were behind the observer, he would have great difficulty in distinguishing the different steps when they are at some distance from the light source. Such conditions are by no means rare and indicate that, in street-lighting specifications for example, computations designed to inquire into those matters in which the brightness sensibility of the eye is concerned should be incorporated.

Another example of a similar nature is that of a staircase illuminated by a single light source over the

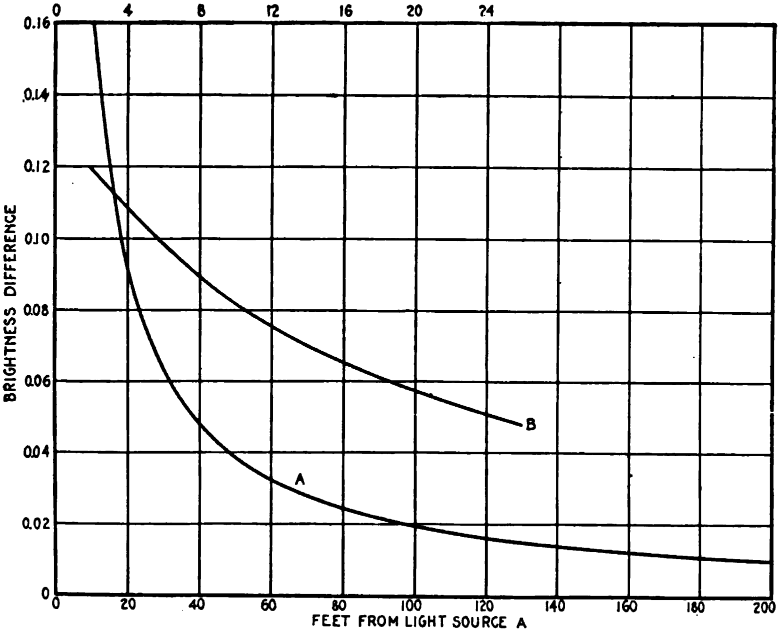


Fig. 116 — Brightness differences that must be perceived in practise. Curve A (lower scale) shows brightness differences between two parallel surfaces one foot apart. Curve B (upper scale) shows brightness differences between adjacent steps of a stairway.

middle at a height ten feet above the plane of the top step. The computed brightness differences of adjacent steps are plotted in curve *B*, Fig. 116. The steps were assumed to have risers eight inches in height; that is, the horizontal planes of adjacent treads were eight inches apart. The brightness differences of successive treads near the top of the stairs are in the neighborhood of ten per cent while near the twentieth step the brightness difference is less than six per cent. The steps are distinguished one from another by an observer descending the stairs, chiefly by brightness differences and perhaps somewhat by irregularities. The steps should be lighted so that the brightness differences are sufficiently high to be easily observed. The conditions presented in curve *B*, Fig. 116, are perhaps just inside the minimum tolerable and the conditions shown in curve *A* are quite undesirable for the greater distances. These examples indicate the importance of light and shade in vision and also the necessity for a recognition of this relation in the practise of lighting.

CHAPTER XIV

LIGHT AND SHADE IN LIGHTING

Inasmuch as lighting can not be separated from any part of the discussion of light and shade, this entire book might be considered as a treatment of lighting; however, a brief discussion of various points that bear especially upon the comparatively new art of illumination has been reserved for this chapter. Light and shade, or the distribution of brightness, is generally the most important factor in vision and is therefore the chief object of lighting. All the effects of lighting upon the appearances of objects which have already been treated in previous chapters are of interest to everybody because they have a bearing upon the use of light which is essential to our most important and educative sense — vision. The profession of illuminating engineering is a comparatively new one, its belated development no doubt being an event of the twentieth century owing to the fact that only in recent years has there been a variety of efficient illuminants available which made it possible for such a profession to develop. Perhaps the greatest criticism that can be applied to the general practise of the art of lighting at present is the lack of proper appreciation of the esthetic possibilities in lighting. The art of lighting is usually practised by engineers and, until these practitioners have had time to develop the knowledge and taste required for the treatment of the art, the other side of the problem, namely the science, is likely to predominate. The condition here is quite the reverse of that found in several of the arts already treated. However, as the profession of lighting grows older, the complete field of the lighting expert is gradually becoming recognized. There are many lighting experts who long ago had begun to realize that proper lighting, although founded upon science as other arts are, has another side, namely, the artistic. The lighting expert must first be fully acquainted with the fundamental scientific principles but he must also be able to look through the eyes of the architect, of the decorator, and of other artists. When the call came for specialists in lighting none was available, and the evolution of such experts began with the engineer as the embryo. For a time the various professions involved worked independently, making mistakes that co-operative efforts would have forestalled, but gradually, as the dependency of the artist and lighting engineer began to be mutually appreciated, better results appeared. It is hardly probable that either will absorb the other because of the magnitude of both professions; instead, as the illuminating engineer develops a knowledge of and a taste for the art of lighting, the lighting expert is evolving. The obvious result is that another expert should be consulted along with the painter, the sculptor, the architect, the decorator, and various engineers in the prosecution of man's works.

The science of illumination has been extensively treated by others but the art has been comparatively neglected. In this chapter light and shade in lighting will be treated chiefly in the indefinite region between the science and the art. The discussions and illustrations in previous chapters are highly applicable here as elementary lessons in lighting but will not be repeated unless necessary; however, there are a few other points of interest that will be touched upon with the hope that the importance of light and shade in lighting will be emphasized.

Light and shade is of considerable interest in the pure utilitarian side of lighting. For instance, shadows and cast shadows play an important part in distinguishing small objects. Diffused light, or light from an extended source, often makes it difficult or even impossible to distinguish such small objects. Small polished objects, such as pins or needles, are often most readily discernible by means of the bright high-lights due to specularly reflected images of light sources. In the foregoing cases direct lighting is obviously the best from the standpoint of distinguishing objects providing the installation is of proper design so that the ability to see is not diminished by glaring light sources in the field of view. In other cases, such as are found in drafting rooms and many factory and office operations, the absence of well-defined shadows is desirable. In such cases diffused light from an extended source is more satisfactory.

Too often the brightness of surroundings is neglected in the consideration of lighting. Surroundings too bright or too dark for a given case produce eye fatigue due to too much or too little light or to excessive contrasts. The brightness sensibility of the eye is obviously affected, as shown in Chapter XIII, by the brightness of the surroundings. In many operations, involving especially the perception of fine detail, the brightness of the background determines the brightness difference between the object and the background which the eye is required to distinguish. Often by changing the background from one of high reflecting power to one of low reflecting power, or vice versa, the ability to see a small object is enhanced. Sometimes the same result could be obtained, although not always as easily, by altering the distribution of light.

In many cases in designing lighting installations the minimum brightness differences which the eye will be required to distinguish should be predetermined, and there should be provided in the final design a sufficiently large factor of safety beyond the limiting brightness sensibility of the retina. This point is illustrated by means of two practical cases in Fig. 116.

The comfort of the eye also depends upon various brightness factors, namely the absolute brightnesses, the brightness contrasts, and the variations of brightness in the entire visual field. Experimental research has not yet determined the safe limits of the foregoing which of course vary with the mean brightness level to which the eye is adapted. The brightness of a clear blue sky is approximately one lambert and can be readily tolerated in the daytime with the eye adapted to the indoor brightness level under proper conditions. In interiors under ordinary artificial lighting, a safe maximum brightness is 250 millilamberts. A safe maximum contrast of two adjacent brightnesses is about 20 to one. This is approximately the ratio of the reflecting power of white paper to that of black ink. The non-uniformity of illumination on the working plane in a given room perhaps should not be greater than 100 to one in the daytime indoors and perhaps considerably less in the case of artificial lighting. The brightness sensibility of the eye is seen in Table IX, under the average conditions outdoors in the daytime, to be less than two per cent and indoors under ordinary artificial lighting conditions to be somewhat above two per cent. The foregoing maximum brightness and contrast are safe limits at least. Perhaps no harm would result in exceeding these somewhat; however, if possible, it is well to remain within the safe limits. Owing to the scanty data available on the foregoing questions it is futile to discuss them extensively. The object in touching upon the foregoing points has been to show that, from the purely utilitarian viewpoint, light and shade is of considerable importance. Variations in brightness are essential to vision, but excessive brightness and brightness contrasts are undesirable and, likewise, insufficient brightness and contrast are not conducive to satisfactory seeing. The desirable medium is the position for which the lighting expert must strive. On making certain that the conditions are within the safe limits, the esthetic sense will determine the distribution of light and shade in those cases where the art is of importance.

It is not the aim in this chapter to present a treatment of the science and art of lighting but to deal with a few of the fundamentals which will aid in visualizing light and shade effects — in general the chief results of lighting. Directed light gives a definite direction to shadows and produces more or less defined shadows depending upon the solid angle subtended by the predominating light source at a given point. In the case of so-called indirect lighting, the light is usually reflected from the ceiling; in such a case the ceiling is the predominant source of light and subtends a large solid angle at any point compared to that of a direct lighting unit. The so-called semi-indirect system is a combination of the so-called direct and indirect lighting systems and might well be called a direct-indirect system of lighting. In such cases two distinctly different shadows cast by objects are one due to the diffusing bowl of the unit and one due to the light from the ceiling. The proportions of the two shadows depend chiefly upon the transmission coefficient of the translucent glass bowl, that is, upon the relative proportions of direct and indirect components. 'Diffused light' is the term usually applied to light which reaches a given point by reflection from various objects, not including the ceiling in the case of indirect lighting. Light that is scattered by a sand-blasted or opal glass is often termed 'diffused light,' so that confusion often arises regarding the meaning of this term. In the following discussion this term will be used to represent that light which reaches a given point from all objects with the exception of the predominant lighting unit.

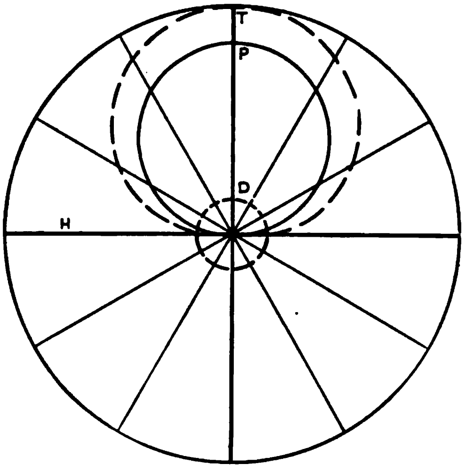


Fig. 117—A diagram of lighting conditions at a point several feet below a direct lighting unit in an ordinary room.

For the purpose of visualizing the foregoing, a direct lighting unit will be assumed so small or so far away from a given point that it is practically a point source and the floor, walls, and ceiling will be considered of approximately uniform reflecting power. Let the point under consideration be at the center of the circle in Fig. 117 and the lighting conditions at this point be studied by means of a small white diffusely reflecting area revolving about an axis through the point and perpendicular to the plane of the paper. The lighting unit is supposed to be hung vertically above the given point. As the small test surface is revolved about the axis its brightness would be found to vary at different angular positions as shown by the curve *P* if there were no diffused light. In fact this curve is a circle tangent to the horizontal plane *H* at the point under consideration. Obviously the maximum brightness of the test surface obtains when it is horizontal and it will have direct light falling upon it only as it is turned through 180 degrees. Diffused light will reach the point by reflection from the floor, walls, ceiling, and other objects. For simplicity, in this case the amount of this diffused light reaching the point is assumed to be constant from all directions and to amount to about 20 per cent as shown by the circle, *D*. The total light reaching the test surface at any given position is represented by the curve *T*. Obviously the conditions would be identical in any other plane. Such conditions are approximated in practise when an object is illuminated by a single, direct lighting unit. In the case of a direct lighting system, consisting of more than one lighting unit, multiple shadows are obtained and the influence of the various direct units must be considered.

In order to illustrate the effect of the reflection coefficient of the surroundings, the simple case of the hollow sphere is taken. If a point source of light of uniform candlepower, *I*, in all directions, be placed at the center of the sphere and the inner surface of the latter be assumed to have a reflection coefficient equal to *R*, the amount of light, *Q*, reaching a given point on this inner surface will bear the following relation

$$Q = Q' + Q'R + Q'R^2 + Q'R^3 + \ldots = \frac{Q'}{1-R}$$

where Q' is the illumination on the inner surface of the sphere due to direct light from the source and is equal to the candle power of the source divided by the square of the radius of the sphere.

If the direct illumination Q' is assumed to be unity, then the relation of the illumination on the inner surface of the sphere to the reflection coefficient of the latter is shown in Fig. 118. The amount of 'diffused light' is found by subtracting the direct light (unity in this case) from the values given on the horizontal scale. The curve obviously is asymptotic to the upper horizontal line. It is seen by this that the reflection coefficient of the surroundings, when large, is responsible for a great deal of the light that reaches a given point in the sphere. However, under ordinary lighting conditions in interiors the amount of diffused light that reaches a given point is usually of the order of magnitude of 5 to 15 per cent.

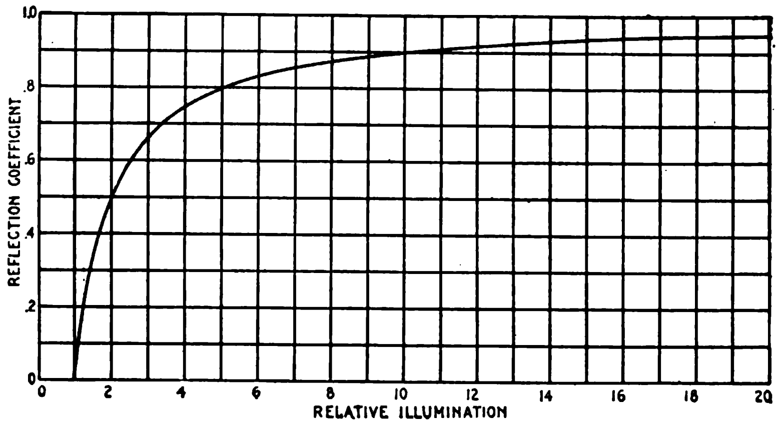


Fig. 118—Showing the effect of multiple reflections and the reflection coefficient in increasing the illumination.

Another important condition in lighting is the case of two direct lighting units placed a certain distance apart. The light and shade effect due to the direct light from the two sources varies with the position of an object between them. Obviously an object midway between the units would be equally illuminated on the two sides respectively facing the units. For simplicity the units are assumed to be ten feet apart which makes it possible to transform the results easily to any distance apart. Theoretically the illumination of an object located at a zero distance from a light source would be infinite. The illumination of the side of the object facing the light source is assumed to be 100 units at a distance of one foot from the light source. The illumination varies inversely as the square of the distance

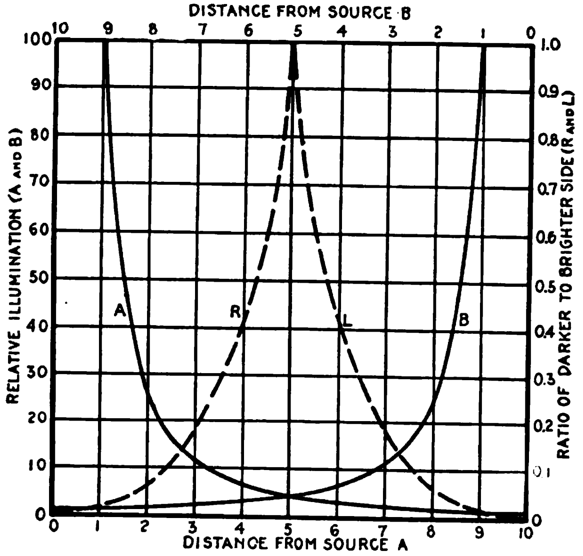


Fig. 119 — Curves A and B represent the relative illuminations (of a vertical plane) due respectively to two light sources ten feet apart. Curves R and L represent the ratios of the illuminations of the two sides (the lesser to the greater).

from the light source and is shown for the two sources by the curves *A* and *B* respectively in Fig. 119. The illuminations of the two sides of a given object which respectively face the two light sources are shown in terms of the ratio of the smaller to the larger for various positions by curves *R* and *L*. In curve *R* one side receives more light and in curve *L* the other side receives more light. It will be noted that this ratio (usually from the standpoint of appearances of objects ratios are of chief importance) changes very rapidly for some positions of the object and less rapidly for others. Similar conditions should be visualized in the contemplation of many distributed direct lighting systems.

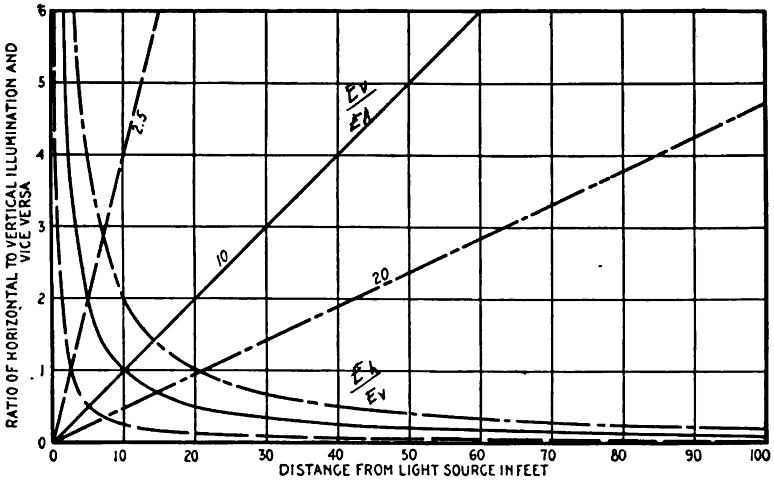


Fig. 120—Influence of the height of the light source on the relative vertical and horizontal illuminations near the horizontal plane.

In Fig. 120 are shown the ratios of the horizontal to the vertical illumination and also the ratios of the vertical to the horizontal illumination at different horizontal distances from a point source of light along a horizontal plane such as a floor or street. These are shown for three heights of the light source, namely, 2.5, 10, and 20 feet. The straight lines represent the ratios of the illumination E_v on the vertical plane of the test surface to that on the horizontal plane E_h and the corresponding curves, the inverse ratios. These conditions cover a considerable range, for examples, from the auto headlight to a reasonably high street lamp.

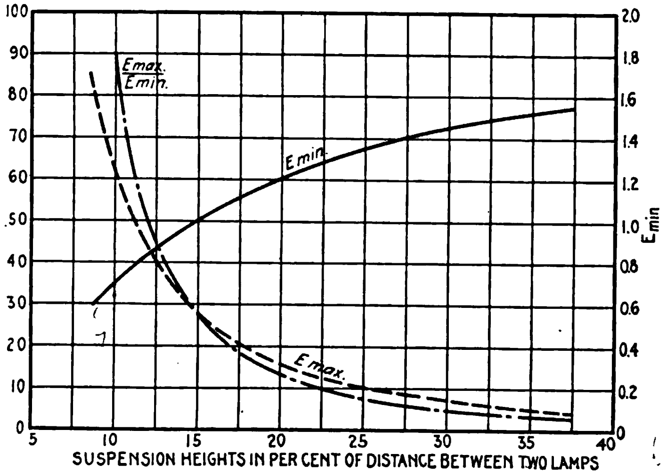


Fig. 121 — Influence of the ratio of suspension heights of lamps to distance between two lamps on the maximum and minimum illuminations on the horizontal plane. The scale for the minimum values is on the right. The scale for the other values is on the left.

In Fig. 121 is shown the variation of certain light and shade conditions for various relations of the height of two light sources above a given plane and their distance apart. The intensity of the light sources are assumed to be uniform in all directions and the minimum and maximum illuminations along the plane were computed. These are shown in the curves as designated and also the ratio of the maximum to the minimum illumination. These are conditions that the lighting expert should be able to visualize approximately in considering any direct lighting installation of a similar nature.

An analysis of the illumination conditions along the horizontal plane between two units hung 10 feet above it and 100 feet apart is presented in Fig. 122. The

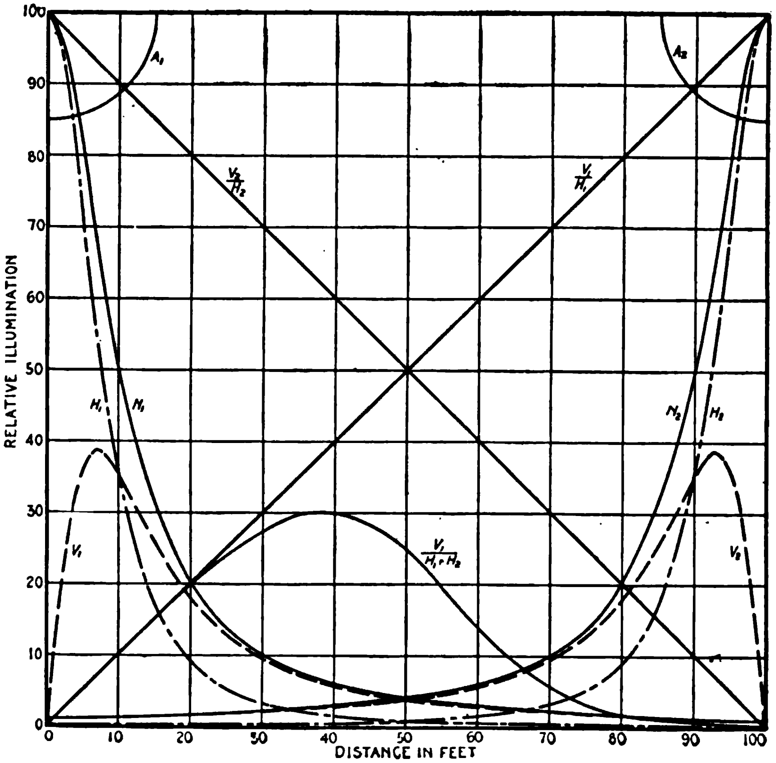


Fig. 122—An analysis of the illumination due to two units, A_1 and A_2, 100 units of distance apart.

light sources are assumed to be of equal intensity in all directions; that is, they have light-distribution curves as shown by A_1 and A_2. The subscripts refer to the two sources respectively. *H, V,* and *N* represent, respectively, the horizontal, vertical, and normal illuminations of a test surface near the horizontal plane.

The normal illumination is that received by a surface placed perpendicular to the line joining the test surface and the light source. It is unnecessary to discuss these data because the results can be best visualized by a study of the curves. The results for sources having non-uniform distribution curves can be readily obtained from the foregoing curves by multiplying points on the latter by the proper ratio.

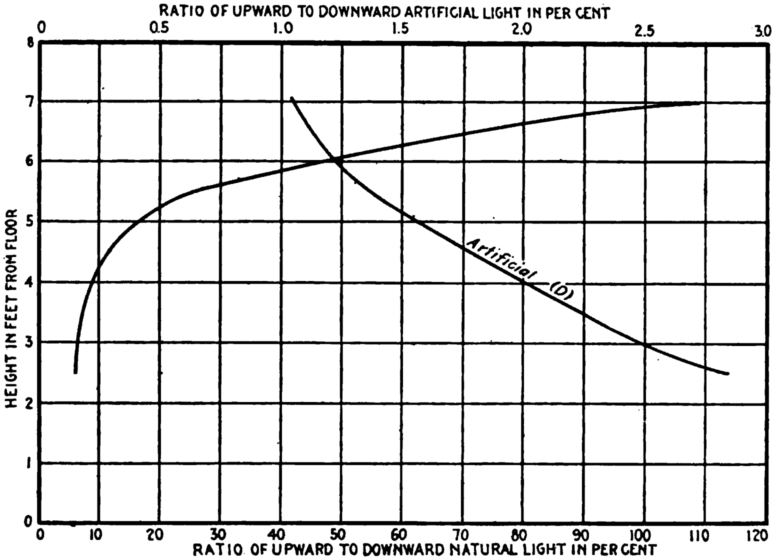


Fig. 123 — Variation of the ratio of upward to downward light with height above the floor in an interior.

Another case of practical interest is shown in Fig. 123, in which a portion of the data obtained in an extensive comparison of the natural and artificial lighting conditions[1] in ordinary interiors is presented. The room was lighted by means of windows on two adjacent sides. In order to show the enormous difference in the distribution of light in a room lighted by means

---

[1] Trans. I. E. S., Oct., 1912, p. 388.

of light from the sky entering ordinary windows and a direct lighting unit near the center of the room, the ratio of the upward to the downward light is chosen. The ceiling and walls of this room were of moderate reflecting power and the floor somewhat less. The measurements were made by means of a horizontal white diffusing surface whose brightnesses on the upper and lower sides were measured at various heights from the floor. It is seen that the results under the two conditions are very different. The ratio of the upward light to the downward light is not only enormously greater for natural lighting through windows but increases with the height of the point considered while this ratio, which is quite small for the artificial lighting system, decreases with the height. The results for all three artificial lighting systems, namely direct, semi-indirect, and indirect, were quite similar and the same general differences between the natural and artificial lighting systems were obtained in rooms differing greatly in furnishings. Many other differences were brought out in the investigation but the foregoing is sufficient to emphasize the greatly different light and shade effects obtained under the two general conditions in such an interior as a whole or in the expression of objects of three dimensions. As already stated these various illustrations have been presented in order to assist in visualizing various conditions found in practise which influence light and shade.

Lighting is not generally enough considered in relation to the architectural and decorative schemes of interiors. The author has given much attention to these relations during the past few years, beginning from the scientific side of lighting with the aim to meet the architect and decorator upon the common ground where architecture, decoration, and lighting intermingle. This study has revealed the magnitude of the possibilities of blending light and shade effects, due entirely to light distribution, into harmony with the decorative plan and the evident lack of co-operation between those responsible for the decoration and for the lighting. In this discussion the artistic design of fixtures is not considered at all because the architect or decorator is usually responsible for these, and color is not considered here because it has already been treated as completely as intended. Only the results of lighting — light and shade — will form the basis of the following brief discussion.

In interiors, objects of two and three dimensions are to be considered. It is often believed that the light and shade of a flat surface is fixed, but this is not true. By the use of pigments of various reflection coefficients the decorator produces a certain brightness distribution apparently independent of the lighting. Nevertheless these surfaces reflect certain percentages of the incident light and their brightnesses will vary with respect to each other depending upon the relative amounts of light falling upon them; that is, upon the distribution of light. Obviously the distribution of light varies enormously depending upon the system installed, so that the work of the decorator is somewhat at the mercy of the lighting expert.

To a greater degree is the work of the architect at the mercy of the lighting. The light and shade of three-dimensional objects is very largely dependent upon the lighting. The shadows shift with the light source, their brightness depends upon the amount of reflected light, and their general character depends upon the size of the dominating light source and its distance. The first general impression of an architectural design is gained through the distribution of large masses of light and shade; the details are considered later. Inasmuch as both the general light and shade effects and the appearance of the details, such as pilasters, capitals, friezes, etc., are influenced enormously by the lighting, the latter should be considered as an intimate part of the design.

The importance of considering the lighting effects in conjunction with the purely architectural design will be emphasized by means of a few examples. Unfortunately it is difficult to obtain photographs that illustrate these points owing both to the limited brightness sensibility of the photographic process compared with that of the eye and to the difficulty of obtaining actual cases which exemplify only one point clearly. However, nearly every interior supplies a lesson, and often many, in the study of lighting results in relation to architecture and decoration. Many simple lessons are found in Chapter IX. One of the chief functions of architecture is to provide shelter and protection, and lighting can often aid in bringing forth such an impression. For instance, assume a large room crossed by beams projecting below the flat ceiling. The spaces between the beams might be either plain or ornamental. If plain, they need not be lighted very brightly but if ornamental the illumination should be sufficient and the lighting system of such a character as to make the ornamental design plainly visible. The lighting units should not directly obscure the design as would be the case with large units hung reasonably close to the ceiling, nor should the lighting units be much brighter than the ceiling in order to avoid obscuring the design by the glare resulting from them. Usually an indirect or semi-indirect unit would illuminate such a ceiling satisfactorily but the height at which such units are hung is important. In this room it is assumed, as is quite usually the case, that the beams and ceiling are of high and practically equal reflecting power. In order for the beams to supply the impression of strength and stability they should be darker than the remainder of the ceiling. They can be made to appear darker either by providing their surfaces with a coating of lower reflection coefficient than the remainder of the ceiling or by illuminating them to a lower intensity. To paint them a darker shade might not always be considered possible by the decorator in his decorative plan. In such a case the lighting can be depended upon to provide the impression of supporting ability or strength. The results are quite the same in either case. In order to obtain the foregoing result by means of lighting, the light sources must be hung between the beams and close enough to the ceiling so that the under side of the beams at least will receive appreciably less light than the remainder of the ceiling. This is briefly an actual condition that was difficult to solve owing to the lack of a definite correlation of architectural design, decoration, and lighting in the early plans. This problem was solved by means of small semi-indirect units of low brightness hung midway between the beams and as far from the ceiling as possible without permitting direct light to illuminate the under side of the beams.

It appears strange that the decorative possibilities of light and shade obtained by means of lighting have barely been recognized by architects and interior decorators. For instance, let us take the case of an actual ornamental ceiling in which one of the recurring elements of the design is a square recess of reasonable size. Such a ceiling would ordinarily be flooded with light, including the prominent beams which enclose square flat areas in the center of which, and of about one half the total area, the recessed squares occur. A so-called semi-indirect unit could be designed to illuminate the latter recesses rather brightly by means of the direct upward light, the remainder of the large square only moderately by means of light from the diffusing glass of the unit, and, if the unit were hung at a proper height, the beams would receive only scattered light. Thus the supporting ability of the beams would be preserved, the decorative treatment of the ceiling would appear entirely harmonious, and general satisfaction would result from the very evident co-operation between the lighting expert, the decorator, and the architect. To obtain the foregoing result a lighting unit must be especially designed but the optical principles involved should present no difficulties to the lighting expert. Symmetry is a keynote in such designs. Why should not the lighting be accurately and designedly symmetrical? The symmetrical arrangement of the ceiling outlets is not sufficient, for it is symmetry in lighting effects and ornamental design that is often necessary to complete the harmony.

Let us consider another case, namely a large dome with a small skylight at the top and arches intersecting the lower portion of the dome on the four sides. Obviously the lighting possibilities can be almost as varied as the general decorative treatnent. A dome can be made to express the spaciousness of outdoors, the mystery of the dark sky, or the shadowless conditions of an overcast day, respectively, by high, low, or moderate brightness. These effects can be enhanced by a proper lighting of the intersecting archways. The whole can be considered as an interior lighted primarily by means of a patch of sky — the skylight — as in the case of the Pantheon at Rome which is lighted through a circular unglazed orifice in the crown of the dome. The entire dome might be faintly lighted from a pedestal at the center of the floor and the shadow of the dome deepened by contrast with the brightly lighted archways. Another treatment which would result in the dome proper being of relatively low brightness would be to light only the archways directly, the dome receiving only a portion of the reflected light. These treatments are simple from a lighting standpoint but the one selected should aid in carrying out the architect's conception. It is obvious that the lighting results might very often tend to defeat the artistic expression conceived by the architect. Too often, even during the first lighting of beautiful architectural works, there is insufficient co-operation between the lighting expert, the architect, and the decorator, and this mistake is very common in the redesign of lighting systems in beautiful old buildings.

In the lighting of large flat areas such as walls, especially when these are covered with mural paintings, the distribution of light often is not carefully considered. It has been shown that the distribution of light on a painting can materially affect the relative values; that is, in Chapter X it was shown that the light and shade of a painting is not completely fixed as is commonly supposed. It is possible by an uneven distribution of light on a mural painting to accentuate its mood beyond that which the artist is able to express by means of pigments owing to the limitations of the latter.

Next let us consider briefly an ordinary residential living room. Such a room has been likened to a picture, the floor representing the foreground; the walls, the middle distance; and the ceiling, the sky. Possibly the general light and shade plan of an interior of this character has evolved through some such mental comparison and partially due to eye comfort. It is true, nevertheless, that ceilings are almost always brighter than the walls and the latter often are gradated in increasing brightness from the bottom toward the top. The floor coverings are often of the same order of brightness as the lower walls. The foregoing brightnesses assume uniform lighting; that is, they are due entirely to different reflection coefficients. If anyone does not believe that the distribution of light in such a room alters the mood or general impression, let him try the experiment first in a room whose walls and ceiling are of fairly high reflecting power. A change from direct to indirect lighting is sufficient to illustrate that the distribution of light very greatly alters the mood of such a room. This effect is not as striking in rooms in which the decorator has partially fixed the light and shade; nevertheless, by means of coatings of rather low reflecting power, the decorator can not entirely eliminate the effect of lighting. Lighting fixtures which make it possible to vary the monotony of artificial lighting should eventually become quite popular. A fixture that is so constructed as to make it possible to flood the upper portion of the room with light, or to localize the light over a library table, thus leaving the remainder of the room in semi-darkness, permits the realization of various moods and relieves monotony by means of various light and shade effects. This is done in well-lighted homes by a combination of proper lighting fixtures and one or more decorative library lamps. This point was brought out in the study of the distribution of brightness in Nature described in Chapter VII.

Fig. 124—Such lighting, an easy chair, and a good book go well together. The localization of the lighting makes reading easy; the softly illuminated surroundings provide areas for occasionally resting the eyes; and the semi-darkness keeps the attention from wandering.

In Figs. 124 and 125 the foregoing is exemplified to some degree by the two different lightings of the same room.

Fig. 125 — In lighting, opportunities should be provided for appreciating an artistically decorated and furnished room as a harmonious whole. Well distributed diffused lighting invites conversation and provides a pleasing environment for family and guests. This illustration and Fig. 124 show the effectiveness of light distribution in altering the general mood of a room.

In a dining room the most important object is the table. Obviously light and shade effects are largely a matter of taste; however, there are few sound arguments for flooding the ceiling of an ordinary dining room with light. Light concentrated on the table with

Fig. 126.—Such diffused lighting makes possible the satisfactory viewing of all objects in the room. If the walls be too bright the decorator can tint them darker shades. This illustration, owing to the uniformity of the brightness of walls and ceiling, suggests that the decorator should carefully consider the distribution of light before deciding upon the wall coverings.

Fig. 127 — The distribution of the natural light in an interior is usually very different from that of the artificial light.

the remainder of the room illuminated by diffused light of a warm tone is an effect quite generally desired and appreciated by students of lighting. The sociability arising among those grouped around the table is fostered by the feeling of being hemmed in by semi-darkness possibly through the primal instinct which

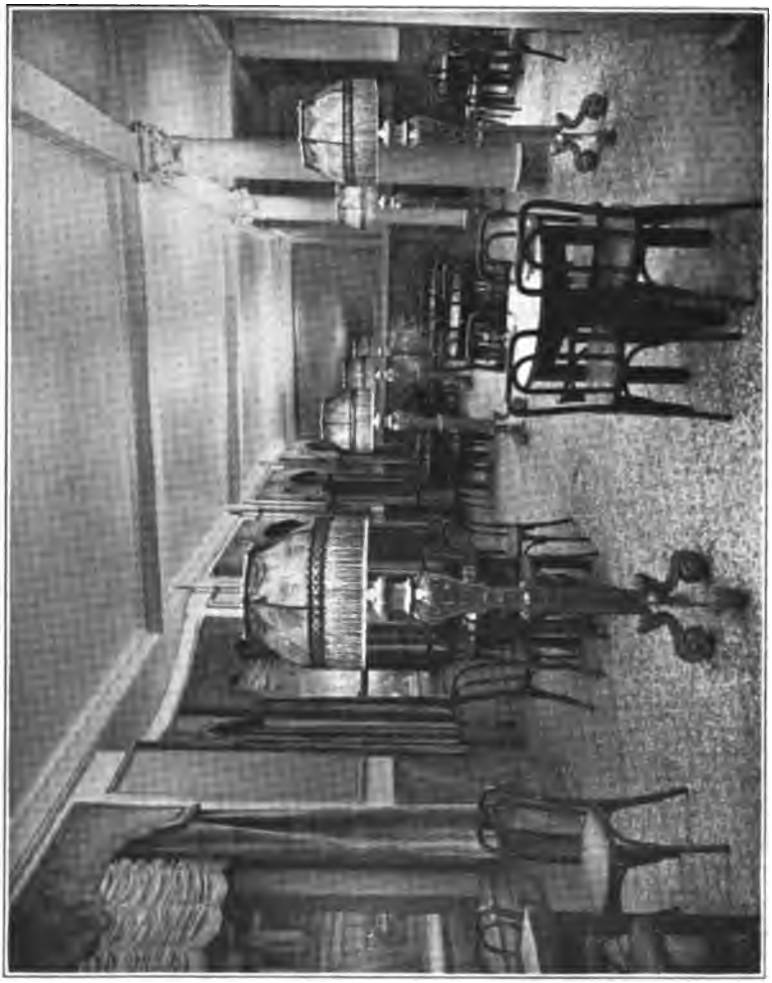


Fig. 128 — This softly diffused lighting, which at no angle gives offense, is an example of extreme restfulness.

Fig. 129 — The beautiful ceiling is well illuminated and yet the view is unobstructed. The mood is light and airy and the whole radiates cheerfulness.

takes one back in imagination to the joy of the campfire. All art appeals partially at least through association with past events. Previous experiences are quite different for different persons so that esthetic tastes can not always coincide. Nevertheless there is a defi-

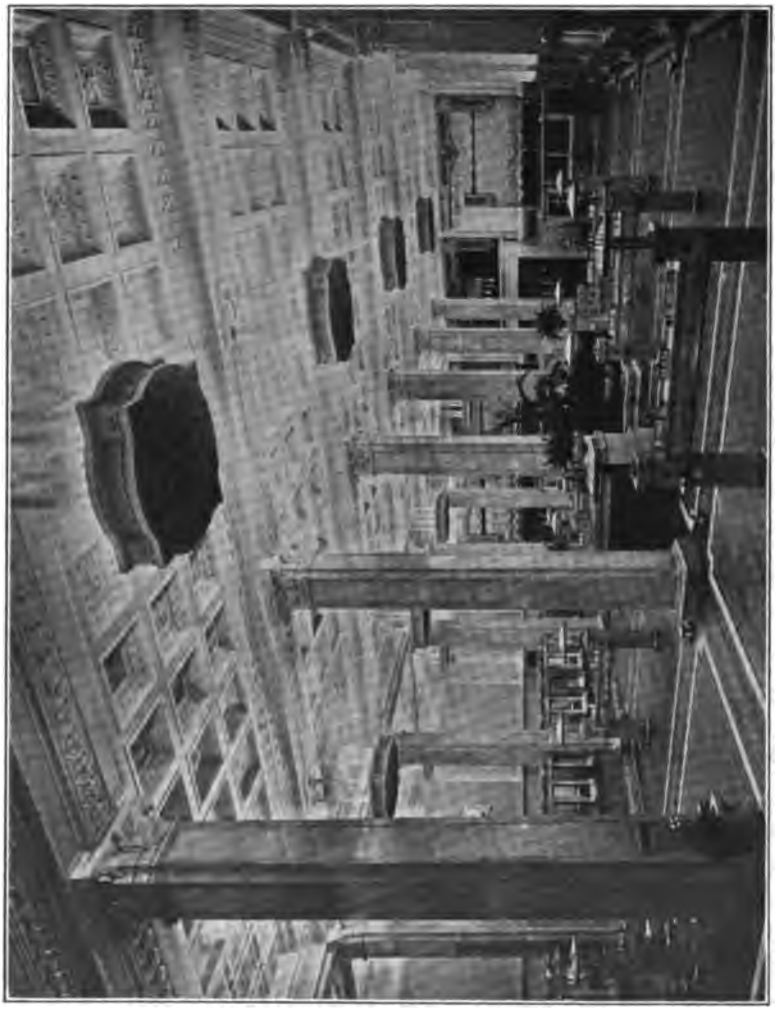


Fig. 130 — This kind of architectural ornament is not obliterated by diffused indirect lighting and it is possible to appreciate the architectural beauty of the whole.

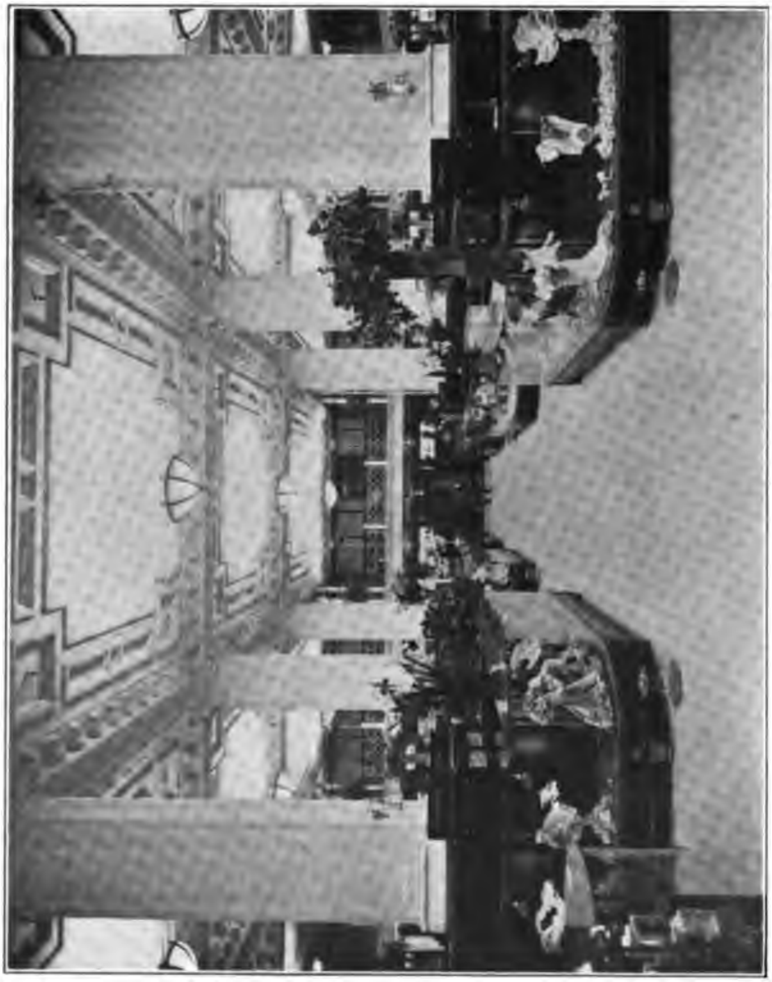


Fig. 131 — This lighting serves several purposes satisfactorily; the ornament is well molded, the displays are uniformly lighted, and the whole impression is attractive and pleasing.

nite distinction between light and shade distributions that are esthetic and those that are unesthetic.

Fig. 132 —Between two dark abysses man worships.

No further attempt will be made to discuss the esthetics of light and shade in lighting, for the chief object has been to point out how such effects can be controlled and to suggest their importance in lighting

Fig. 133 — The concealed lighting reveals the beautiful ornaments and is befittingly adapted to such a church.

Fig. 134 — The lighting patterns the impressive vaulted arches in light and shade with a resulting solemnity.

both from the utilization and artistic standpoints. The illustrations in Figs. 124 to 135 are presented to show the great possibilities in light and shade effects. The results, as feebly shown photographically, can be best interpreted by each individual for himself. A variety of

Fig. 135 — The diffused lighting reveals the beauty of the interior yet does not obliterate the ornament. The bright surroundings inspire cheerfulness and symbolize enlightenment.

photographs have been chosen which represent many different moods and relations of lighting to the general architectural and decorative plans.

Further acknowledgments.

For some of the photographs of lighting installations the author is indebted to

The National X-Ray Reflector Co.
The Ivanhoe-Regent Works of General Electric Co.
The National Lamps Works of General Electric Co.
The Illuminating Department of the General Electric Co.

INDEX

D. VAN NOSTRAND COMPANY
25 PARK PLACE
NEW YORK

SHORT-TITLE CATALOG
OF
Publications and Importations
OF
SCIENTIFIC AND ENGINEERING BOOKS

This list includes all the books published by the
M. C. CLARK PUBLISHING CO.,
Chicago, Ill.,
and the technical publications of the following English publishers:
SCOTT, GREENWOOD & CO. JAMES MUNRO & CO., Ltd.
CONSTABLE & COMPANY, Ltd. TECHNICAL PUBLISHING CO.
ELECTRICIAN PRINTING & PUBLISHING CO.
for whom D. Van Nostrand Company are American agents.

MARCH, 1916

SHORT-TITLE CATALOG
OF THE
Publications and Importations
OF
D. VAN NOSTRAND COMPANY
25 PARK PLACE, N. Y.

The books published by the
MYRON C. CLARK PUBLISHING CO., Chicago, Ill.
are included in this catalog.

Prices marked with an asterisk (*) are NET.
All bindings are in cloth unless otherwise noted.

Abbott, A. V. The Electrical Transmission of Energy	8vo,	*$5 00
—— A Treatise on Fuel. (Science Series No. 9.)	16mo,	0 50
—— Testing Machines. (Science Series No. 74.)	16mo,	0 50
Adam, P. Practical Bookbinding. Trans. by T. E. Maw	12mo,	*2 50
Adams, H. Theory and Practice in Designing	8vo,	*2 50
Adams, H. C. Sewage of Sea Coast Towns	8vo	*2 00
Adams, J. W. Sewers and Drains for Populous Districts	8vo,	2 50
Addyman, F. T. Practical X-Ray Work	8vo,	*4 00
Adler, A. A. Theory of Engineering Drawing	8vo,	*2 00
—— Principles of Parallel Projecting-line Drawing	8vo,	*1 00
Aikman, C. M. Manures and the Principles of Manuring	8vo,	2 50
Aitken, W. Manual of the Telephone	8vo,	*8 00
d'Albe, E. E. F., Contemporary Chemistry	12mo,	*1 25
Alexander, J. H. Elementary Electrical Engineering	12mo,	2 00
Allan, W. Strength of Beams Under Transverse Loads. (Science Series No. 19.)	16mo,	0 50
—— Theory of Arches. (Science Series No. 11.)	16mo,	
Allen, H. Modern Power Gas Producer Practice and Applications	12mo,	*2 50
—— Gas and Oil Engines	8vo,	*4 50
Anderson, F. A. Boiler Feed Water	8vo,	*2 50
Anderson, Capt. G. L. Handbook for the Use of Electricians	8vo,	3 00
Anderson, J. W. Prospector's Handbook	12mo,	1 50
Andés, L. Vegetable Fats and Oils	8vo,	*4 00
—— Animal Fats and Oils. Trans. by C. Salter	8vo,	*4 00
—— Drying Oils, Boiled Oil, and Solid and Liquid Driers	8vo,	*5 00
—— Iron Corrosion, Anti-fouling and Anti-corrosive Paints. Trans. by C. Salter	8vo,	*4 00
Andés, L. Oil Colors, and Printers' Ink. Trans. by A. Morris and H. Robson	8vo,	*2 50

Andés, L. Treatment of Paper for Special Purposes. Trans. by C. Salter. 12mo,	*2 50
Andrews, E. S. Reinforced Concrete Construction.............12mo,	*1 25
—— Theory and Design of Structures..........................8vo,	*3 50
—— Further Problems in the Theory and Design of Structures....8vo,	*2 50
Andrews, E. S., and Heywood, H. B. The Calculus for Engineers.12mo,	*1 25
Annual Reports on the Progress of Chemistry. Twelve Volumes now ready. Vol. I., 1904, Vol. XII., 1914................8vo, each,	*2 00
Argand, M. Imaginary Quantities. Translated from the French by A. S. Hardy. (Science Series No. 52.)..................16mo,	0 50
Armstrong, R., and Idell, F. E. Chimneys for Furnaces and Steam Boilers. (Science Series No. 1.)..............................16mo,	0 50
Arnold, E. Armature Windings of Direct-Current Dynamos. Trans. by F. B. DeGress...8vo,	*2 00
Asch, W., and Asch, D. The Silicates in Chemistry and Commerce.8vo,	*6 00
Ashe, S. W., and Keiley, J. D. Electric Railways. Theoretically and Practically Treated. Vol. I. Rolling Stock..............12mo,	*2 50
Ashe, S. W. Electric Railways. Vol. II. Engineering Preliminaries and Direct Current Sub-Stations.........................12mo,	*2 50
—— Electricity: Experimentally and Practically Applied..........12mo,	*2 00
Ashley, R. H. Chemical Calculations..........................12mo,	*2 00
Atkins, W. Common Battery Telephony Simplified.............12mo,	*1 25
Atkinson, A. A. Electrical and Magnetic Calculations..............8vo,	*1 50
Atkinson, J. J. Friction of Air in Mines. (Science Series No. 14.)..16mo,	0 50
Atkinson, J. J., and Williams, Jr., E. H. Gases Met with in Coal Mines. (Science Series No. 13.)...............................16mo,	0 55
Atkinson, P. The Elements of Electric Lighting.................12mo,	1 00
—— The Elements of Dynamic Electricity and Magnetism........12mo,	2 00
—— Power Transmitted by Electricity..........................12mo,	2 00
Auchincloss, W. S. Link and Valve Motions Simplified.............8vo,	*1 50
Austin, E. Single Phase Electric Railways.....................4to,	*5 00
Ayrton, H. The Electric Arc.......................................8vo,	*5 00
Bacon, F. W. Treatise on the Richards Steam-Engine Indicator ..12mo,	1 00
Bailes, G. M. Modern Mining Practice. Five Volumes ....8vo, each,	3 50
Bailey, R. D. The Brewers' Analyst............................8vo,	*5 00
Baker, A. L. Quaternions..8vo,	*1 25
—— Thick-Lens Optics..12mo,	*1 50
Baker, Benj. Pressure of Earthwork. (Science Series No. 56.)...16mo,	
Baker, I. O. Levelling. (Science Series No. 91.)................16mo,	0 50
Baker, M. N. Potable Water. (Science Series No. 61.)...........16mo,	0 50
—— Sewerage and Sewage Purification. (Science Series No. 18.)..16mo,	0 50
Baker, T. T. Telegraphic Transmission of Photographs..........12mo,	*1 25
Bale, G. R. Modern Iron Foundry Practice. Two Volumes. 12mo.	
Vol. I. Foundry Equipment, Materials Used......................	*2 50
Vol. II. Machine Moulding and Moulding Machines................	*1 50
Ball, J. W. Concrete Structures in Railways.................8vo,	*2 50
Ball, R. S. Popular Guide to the Heavens.......................8vo,	*4 50
—— Natural Sources of Power. (Westminster Series.) 8vo,	*2 00
Ball, W. V. Law Affecting Engineers..........................8vo,	*3 50

Bankson, Lloyd. Slide Valve Diagrams. (Science Series No. 108.) 16mo,	0 50
Barba, J. Use of Steel for Constructive Purposes 12mo,	1 00
Barham, G. B. Development of the Incandescent Electric Lamp 8vo,	*2 00
Barker, A. F. Textiles and Their Manufacture. (Westminster Series.) 8vo,	2 00
Barker, A. F., and Midgley, E. Analysis of Textile Fabrics 8vo,	3 00
Barker, A. H. Graphic Methods of Engine Design 12mo,	*1 50
—— Heating and Ventilation 4to,	*8 00
Barnard, J. H. The Naval Militiaman's Guide 16mo, leather	1 00
Barnard, Major J. G. Rotary Motion. (Science Series No. 90.) 16mo,	0 50
Barrus, G. H. Boiler Tests 8vo,	*3 00
—— Engine Tests 8vo,	*4 00
The above two purchased together	*6 00
Barwise, S. The Purification of Sewage 12mo,	3 50
Baterden, J. R. Timber. (Westminster Series.) 8vo,	*2 00
Bates, E. L., and Charlesworth, F. Practical Mathematics 12mo,	
Part I. Preliminary and Elementary Course	*1 50
Part II. Advanced Course	*1 50
—— Practical Mathematics 12mo,	*1 50
—— Practical Geometry and Graphics 12mo,	*2 00
Batey, J. The Science of Works Management 12mo,	*1 25
Beadle, C. Chapters on Papermaking. Five Volumes 12mo, each,	*2 00
Beaumont, R. Color in Woven Design 8vo,	*6 00
—— Finishing of Textile Fabrics 8vo,	*4 00
Beaumont, W. W. The Steam-Engine Indicator 8vo,	2 50
Bechhold, H. Colloids in Biology and Medicine. Trans. by J. G. Bullowa (*In Press.*)	
Beckwith, A. Pottery 8vo, paper,	0 60
Bedell, F., and Pierce, C. A. Direct and Alternating Current Manual. 8vo,	*2 00
Beech, F. Dyeing of Cotton Fabrics 8vo,	*3 00
—— Dyeing of Woolen Fabrics 8vo,	*3 50
Begtrup, J. The Slide Valve 8vo,	*2 00
Beggs, G. E. Stresses in Railway Girders and Bridges (*In Press.*)	
Bender, C. E. Continuous Bridges. (Science Series No. 26.) 16mo,	0 50
—— Proportions of Pins used in Bridges. (Science Series No. 4.) 16mo,	0 50
Bengough, G. D. Brass. (Metallurgy Series.) (*In Press.*)	
Bennett, H. G. The Manufacture of Leather 8vo,	*4 50
Bernthsen, A. A Text-book of Organic Chemistry. Trans. by G. M'Gowan 12mo,	*2 50
Berry, W. J. Differential Equations of the First Species. 12mo. (*In Preparation.*)	
Bersch, J. Manufacture of Mineral and Lake Pigments. Trans. by A. C. Wright 8vo,	*5 00
Bertin, L. E. Marine Boilers. Trans. by L. S. Robertson 8vo,	5 00
Beveridge, J. Papermaker's Pocket Book 12mo,	*4 00
Binnie, Sir A. Rainfall Reservoirs and Water Supply 8vo,	*3 00
Binns, C. F. Manual of Practical Potting 8vo,	*7 50
—— The Potter's Craft 12mo,	*2 00
Birchmore, W. H. Interpretation of Gas Analysis 12mo,	*1 25
Blaine, R. G. The Calculus and Its Applications 12mo,	*1 50

Blake, W. H. Brewers' Vade Mecum	8vo,	*4 00
Blasdale, W. C. Quantitative Chemical Analysis. (Van Nostrand's Textbooks.)	12mo,	*2 50
Bligh, W. G. The Practical Design of Irrigation Works	8vo,	*6 00
Bloch, L. Science of Illumination. Trans. by W. C. Clinton	8vo,	*2 50
Blok, A. Illumination and Artificial Lighting	12mo,	1 25
Blücher, H. Modern Industrial Chemistry. Trans. by J. P. Millington.	8vo,	*7 50
Blyth, A. W. Foods: Their Composition and Analysis	8vo,	7 50
—— Poisons: Their Effects and Detection	8vo,	7 50
Böckmann, F. Celluloid	12mo,	*2 50
Bodmer, G. R. Hydraulic Motors and Turbines	12mo,	5 00
Boileau, J. T. Traverse Tables	8vo,	5 00
Bonney, G. E. The Electro-platers' Handbook	12mo,	1 20
Booth, N. Guide to the Ring-spinning Frame	12mo,	*1 25
Booth, W. H. Water Softening and Treatment	8vo,	*2 50
—— Superheaters and Superheating and Their Control	8vo,	*1 50
Bottcher, A. Cranes: Their Construction, Mechanical Equipment and Working. Trans. by A. Tolhausen	4to,	*10 00
Bottler, M. Modern Bleaching Agents. Trans. by C. Salter	12mo,	*2 50
Bottone, S. R. Magnetos for Automobilists	12mo,	*1 00
Boulton, S. B. Preservation of Timber. (Science Series No. 82.)	16mo,	0 50
Bourcart, E. Insecticides, Fungicides and Weedkillers	8vo,	*4 50
Bourgougnon, A. Physical Problems. (Science Series No. 113.)	16mo,	0 50
Bourry, E. Treatise on Ceramic Industries. Trans. by A. B. Searle.	8vo,	*5 00
Bowie, A. J., Jr. A Practical Treatise on Hydraulic Mining	8vo,	5 00
Bowles, O. Tables of Common Rocks. (Science Series No. 125.)	16mo,	0 50
Bowser, E. A. Elementary Treatise on Analytic Geometry	12mo,	1 75
—— Elementary Treatise on the Differential and Integral Calculus	12mo,	2 25
—— Elementary Treatise on Analytic Mechanics	12mo,	3 00
—— Elementary Treatise on Hydro-mechanics	12mo,	2 50
—— A Treatise on Roofs and Bridges	12mo,	*2 25
Boycott, G. W. M. Compressed Air Work and Diving	8vo,	*4.00
Bragg, E. M. Marine Engine Design.	12mo,	*2 00
—— Design of Marine Engines and Auxiliaries	(*In Press.*)	
Brainard, F. R. The Sextant. (Science Series No. 101.)	16mo,	
Brassey's Naval Annual for 1915	8vo,	
Brew, W. Three-Phase Transmission	8vo,	*2 00
Briggs, R., and Wolff, A. R. Steam-Heating. (Science Series No. 67.)	16mo,	0 50
Bright, C. The Life Story of Sir Charles Tilson Bright	8vo,	*4 50
Brislee, T. J. Introduction to the Study of Fuel. (Outlines of Industrial Chemistry.)	8vo,	*3 00
Broadfoot, S. K. Motors, Secondary Batteries. (Installation Manuals Series.)	12mo,	*0 75
Broughton, H. H. Electric Cranes and Hoists		*9 00
Brown, G. Healthy Foundations. (Science Series No. 80.)	16mo,	0 50
Brown, H. Irrigation	8vo,	*5 00
Brown, Wm. N. The Art of Enamelling on Metal	12mo,	*1 00

Brown, Wm. N. Dipping, Burnishing, Lacquering and Bronzing Brass Ware	12mo,	*1 00
—— Handbook on Japanning and Enamelling	12mo,	*1 50
—— House Decorating and Painting	12mo,	*1 50
—— History of Decorative Art	12mo,	*1 25
—— Workshop Wrinkles	8vo,	*1 00
Browne, C. L. Fitting and Erecting of Engines	8vo,	*1 50
Browne, R. E. Water Meters. (Science Series No. 81.)	16mo,	0 50
Bruce, E. M. Pure Food Tests	12mo,	*1 25
Bruhns, Dr. New Manual of Logarithms	8vo, cloth,	2 00
	half morocco,	2 50
Brunner, R. Manufacture of Lubricants, Shoe Polishes and Leather Dressings. Trans. by C. Salter	8vo,	*3 00
Buel, R. H. Safety Valves. (Science Series No. 21.)	16mo,	0 50
Burley, G. W. Lathes, Their Construction and Operation	12mo,	1 25
Burstall, F. W. Energy Diagram for Gas. With Text	8vo,	1 50
—— Diagram. Sold separately		*1 00
Burt, W. A. Key to the Solar Compass	16mo, leather,	2 50
Buskett, E. W. Fire Assaying	12mo,	*1 25
Butler, H. J. Motor Bodies and Chassis	8vo,	*2 50
Byers, H. G., and Knight, H. G. Notes on Qualitative Analysis	8vo,	*1 50

Cain, W. Brief Course in the Calculus	12mo,	*1 75
—— Elastic Arches. (Science Series No. 48.)	16mo,	0 50
—— Maximum Stresses. (Science Series No. 38.)	16mo,	0 50
—— Practical Designing Retaining of Walls. (Science Series No. 3.)	16mo,	0 50
—— Theory of Steel-concrete Arches and of Vaulted Structures. (Science Series No. 42.)	16mo,	0 50
—— Theory of Voussoir Arches. (Science Series No. 12.)	16mo,	0 50
—— Symbolic Algebra. (Science Series No. 73.)	16mo,	0 50
Carpenter, F. D. Geographical Surveying. (Science Series No. 37.)	16mo,	
Carpenter, R. C., and Diederichs, H. Internal Combustion Engines	8vo,	*5 00
Carter, E. T. Motive Power and Gearing for Electrical Machinery	8vo,	3 50
Carter, H. A. Ramie (Rhea), China Grass	12mo,	*2 00
Carter, H. R. Modern Flax, Hemp, and Jute Spinning	8vo,	*3 00
—— Bleaching, Dyeing and Finishing of Fabrics	8vo,	*1 00
Cary, E. R. Solution of Railroad Problems with the Slide Rule	16mo,	*1 00
Cathcart, W. L. Machine Design. Part I. Fastenings	8vo,	*3 00
Cathcart, W. L., and Chaffee, J. I. Elements of Graphic Statics	8vo,	*3 00
—— Short Course in Graphics	12mo,	1 50
Caven, R. M., and Lander, G. D. Systematic Inorganic Chemistry	12mo,	*2 00
Chalkley, A. P. Diesel Engines	8vo,	*3 00
Chambers' Mathematical Tables	8vo,	1 75
Chambers, G. F. Astronomy	16mo,	*1 50
Charpentier, P. Timber	8vo,	*6 00
Chatley, H. Principles and Designs of Aeroplanes. (Science Series No. 126)	16mo,	0 50
—— How to Use Water Power	12mo,	*1 00
—— Gyrostatic Balancing	8vo,	*1 00

Child, C. D. Electric Arc	8vo,	*2 00
Child, C. T. The How and Why of Electricity	12mo,	1 00
Christian, M. Disinfection and Disinfectants. Trans. by Chas. Salter	12mo,	2 00
Christie, W. W. Boiler-waters, Scale, Corrosion, Foaming	8vo,	*3 00
—— Chimney Design and Theory	8vo,	*3 00
—— Furnace Draft. (Science Series No. 123.)	16mo,	0 50
—— Water: Its Purification and Use in the Industries	8vo,	*2 00
Church's Laboratory Guide. Rewritten by Edward Kinch	8vo,	*2 50
Clapperton, G. Practical Papermaking	8vo,	2 50
Clark, A. G. Motor Car Engineering.		
Vol. I. Construction		*3 00
Vol. II. Design	*(In Press.)*	
Clark, C. H. Marine Gas Engines	12mo,	*1 50
Clark, J. M. New System of Laying Out Railway Turnouts	12mo,	1 00
Clarke, J. W., and Scott, W. Plumbing Practice.		
Vol. I. Lead Working and Plumbers' Materials	8vo,	*4 00
Vol. II. Sanitary Plumbing and Fittings	*(In Press.)*	
Vol. III. Practical Lead Working on Roofs	*(In Press.)*	
Clausen-Thue, W. A B C Telegraphic Code. Fourth Edition	12mo,	*5 00
Fifth Edition	8vo,	*7 00
—— The A 1 Telegraphic Code	8vo,	*7 50
Clerk, D., and Idell, F. E. Theory of the Gas Engine. (Science Series No. 62.)	16mo,	0 50
Clevenger, S. R. Treatise on the Method of Government Surveying.	16mo, morocco,	2 50
Clouth, F. Rubber, Gutta-Percha, and Balata	8vo,	*5 00
Cochran, J. Concrete and Reinforced Concrete Specifications	8vo,	*2 50
—— Inspection of Concrete Construction	8vo,	*4 00
—— Treatise on Cement Specifications	8vo,	*1 00
Coffin, J. H. C. Navigation and Nautical Astronomy	12mo,	*3 50
Colburn, Z., and Thurston, R. H. Steam Boiler Explosions. (Science Series No. 2.)	16mo,	0 50
Cole, R. S. Treatise on Photographic Optics	12mo,	1 50
Coles-Finch, W. Water, Its Origin and Use	8vo,	*5 00
Collins, J. E. Useful Alloys and Memoranda for Goldsmiths, Jewelers.	16mo,	0 50
Collis, A. G. High and Low Tension Switch-Gear Design	8vo,	*3 50
—— Switchgear. (Installation Manuals Series.)	12mo,	*0 50
Comstock, D. F., and Toland, L. T. Modern Theory of the Constitution of Matter	*(In Press.)*	
Constantine, E. Marine Engineers, Their Qualifications and Duties.	8vo,	*2 00
Coombs, H. A. Gear Teeth. (Science Series No. 120.)	16mo,	0 50
Cooper, W. R. Primary Batteries	8vo,	*4 00
Copperthwaite, W. C. Tunnel Shields	4to,	*9 00
Corey, H. T. Water Supply Engineering	8vo *(In Press.)*	
Corfield, W. H. Dwelling Houses. (Science Series No. 50.)	16mo,	0 50
—— Water and Water-Supply. (Science Series No. 17.)	16mo,	0 50
Cornwall, H. B. Manual of Blow-pipe Analysis	8vo,	*2 50

Courtney, C. F. Masonry Dams 8vo,	3 50
Cowell, W. B. Pure Air, Ozone, and Water 12mo,	*2 00
Craig, J. W., and Woodward, W. P. Questions and Answers About Electrical Apparatus 12mo, leather,	1 50
Craig, T. Motion of a Solid in a Fuel. (Science Series No. 49.) 16mo,	0 50
—— Wave and Vortex Motion. (Science Series No. 43.) 16mo,	0 50
Cramp, W. Continuous Current Machine Design 8vo,	*2 50
Creedy, F. Single Phase Commutator Motors 8vo,	*2 00
Crocker, F. B. Electric Lighting. Two Volumes. 8vo.	
Vol. I. The Generating Plant	3 00
Vol. II. Distributing Systems and Lamps	
Crocker, F. B., and Arendt, M. Electric Motors 8vo,	*2 50
Crocker, F. B., and Wheeler, S. S. The Management of Electrical Machinery 12mo,	*1 00
Cross, C. F., Bevan, E. J., and Sindall, R. W. Wood Pulp and Its Applications. (Westminster Series.) 8vo,	*2 00
Crosskey, L. R. Elementary Perspective 8vo,	1 00
Crosskey, L. R., and Thaw, J. Advanced Perspective 8vo,	1 50
Culley, J. L. Theory of Arches. (Science Series No. 87.) 16mo,	0 50
Dadourian, H. M. Analytical Mechanics 12mo,	*3 00
Dana, R. T. Handbook of Construction plant 12mo, leather,	*5 00
Danby, A. Natural Rock Asphalts and Bitumens 8vo,	*2 50
Davenport, C. The Book. (Westminster Series.) 8vo,	*2 00
Davey, N. The Gas Turbine 8vo,	*4 00
Davies, F. H. Electric Power and Traction 8vo,	*2 00
—— Foundations and Machinery Fixing. (Installation Manual Series.) 6mo,	*1 00
Dawson, P. Electric Traction on Railways 8vo,	*9 00
Deerr, N. Sugar Cane 8vo,	*7 00
Deite, C. Manual of Soapmaking. Trans. by S. T. King 4to,	*5 00
De la Coux, H. The Industrial Uses of Water. Trans. by A. Morris. 8vo,	*4 50
Del Mar, W. A. Electric Power Conductors 8vo,	*2 00
Denny, G. A. Deep-level Mines of the Rand 4to,	*10 00
—— Diamond Drilling for Gold	*5 00
De Roos, J. D. C. Linkages. (Science Series No. 47.) 16mo,	0 50
Derr, W. L. Block Signal Operation Oblong 12mo,	*1 50
—— Maintenance-of-Way Engineering (*In Preparation.*)	
Desaint, A. Three Hundred Shades and How to Mix Them 8vo,	*8 00
De Varona, A. Sewer Gases. (Science Series No. 55.) 16mo,	0 50
Devey, R. G. Mill and Factory Wiring. (Installation Manuals Series.) 12mo,	*1 00
Dibdin, W. J. Purification of Sewage and Water 8vo,	6 50
Dichmann, Carl. Basic Open-Hearth Steel Process 12mo,	*3 50
Dieterich, K. Analysis of Resins, Balsams, and Gum Resins 8vo,	*3 00
Dinger, Lieut. H. C. Care and Operation of Naval Machinery 12mo,	*2 00
Dixon, D. B. Machinist's and Steam Engineer's Practical Calculator. 16mo, morocco,	1 25
Doble, W. A. Power Plant Construction on the Pacific Coast (*In Press.*)	

Dodge, G. F. Diagrams for Designing Reinforced Concrete Structures,	folio,	*4 00
Dommett, W. E. Motor Car Mechanism	12mo,	*1 25
Dorr, B. F. The Surveyor's Guide and Pocket Table-book.	16mo, morocco,	2 00
Down, P. B. Handy Copper Wire Table	16mo,	*1 00
Draper, C. H. Elementary Text-book of Light, Heat and Sound	12mo,	1 00
—— Heat and the Principles of Thermo-dynamics	12mo,	*2 00
Dron, R. W. Mining Formulas	12mo,	1 00
Dubbel, H. High Power Gas Engines	8vo,	*5 00
Duckwall, E. W. Canning and Preserving of Food Products	8vo,	*5 00
Dumesny, P., and Noyer, J. Wood Products, Distillates, and Extracts.	8vo,	*4 50
Duncan, W. G., and Penman, D. The Electrical Equipment of Collieries.	8vo,	*4 00
Dunstan, A. E., and Thole, F. B. T. Textbook of Practical Chemistry.	12mo,	*1 40
Duthie, A. L. Decorative Glass Processes. (Westminster Series.)	8vo,	*2 00
Dwight, H. B. Transmission Line Formulas	8vo,	*2 00
Dyson, S. S. Practical Testing of Raw Materials	8vo,	*5 00
Dyson, S. S., and Clarkson, S. S. Chemical Works	8vo,	*7 50
Eccles, R. G., and Duckwall, E. W. Food Preservatives	8vo, paper,	0 50
Eccles, W. H. Wireless Telegraphy and Telephony	12mo,	*4 50
Eck, J. Light, Radiation and Illumination. Trans. by Paul Hogner,	8vo,	*2 50
Eddy, H. T. Maximum Stresses under Concentrated Loads	8vo,	1 50
Edelman, P. Inventions and Patents 12mo.	12mo,	*1 50
Edgcumbe, K. Industrial Electrical Measuring Instruments	8vo,	
Edler, R. Switches and Switchgear. Trans. by Ph. Laubach	8vo,	*4 00
Eissler, M. The Metallurgy of Gold	8vo,	7 50
—— The Metallurgy of Silver	8vo,	4 00
—— The Metallurgy of Argentiferous Lead	8vo,	5 00
—— A Handbook on Modern Explosives	8vo,	5 00
Ekin, T. C. Water Pipe and Sewage Discharge Diagrams	folio,	*3 00
Electric Light Carbons, Manufacture of	8vo,	1 00
Eliot, C. W., and Storer, F. H. Compendious Manual of Qualitative Chemical Analysis	12mo,	*1 25
Ellis, C. Hydrogenation of Oils	8vo,	*4 00
Ellis, G. Modern Technical Drawing	8vo,	*2 00
Ennis, Wm. D. Linseed Oil and Other Seed Oils	8vo,	*4 00
—— Applied Thermodynamics	8vo,	*4 50
—— Flying Machines To-day	12mo,	*4 50
—— Vapors for Heat Engines	12mo,	*1 00
Erfurt, J. Dyeing of Paper Pulp. Trans. by J. Hubner		
Ermen, W. F. A. Materials Used in Sizing	8vo,	*2 00
Erwin, M. The Universe and the Atom	12mo,	*2 00
Evans, C. A. Macadamized Roads	*(In Press.)*	

Ewing, A. J. Magnetic Induction in Iron	8vo,	*4 00
Fairie, J. Notes on Lead Ores	12mo,	*1 00
—— Notes on Pottery Clays	12mo,	*1 50
Fairley, W., and Andre, Geo. J. Ventilation of Coal Mines. (Science Series No. 58.)	16mo,	0 50
Fairweather, W. C. Foreign and Colonial Patent Laws	8vo,	*3 00
Falk, M. S. Cement Mortars and Concretes	8vo,	*2 50
Fanning, J. T. Hydraulic and Water-supply Engineering	8vo,	*5 00
Fay, I. W. The Coal-tar Colors	8vo,	*4 00
Fernbach, R. L. Glue and Gelatine	8vo,	*3 00
—— Chemical Aspects of Silk Manufacture	12mo,	*1 00
Fischer, E. The Preparation of Organic Compounds. Trans. by R. V. Stanford	12mo,	*1 25
Fish, J. C. L. Lettering of Working Drawings	Oblong 8vo,	1 00
—— Mathematics of the Paper Location of a Railroad	paper, 12mo,	*0 25
Fisher, H. K. C., and Darby, W. C. Submarine Cable Testing	8vo,	*3 50
Fleischmann, W. The Book of the Dairy. Trans. by C. M. Aikman.	8vo,	4 00
Fleming, J. A. The Alternate-current Transformer. Two Volumes. 8vo.		
Vol. I. The Induction of Electric Currents		*5 00
Vol. II. The Utilization of Induced Currents		*5 00
Fleming, J. A. Propagation of Electric Currents	8vo,	*3 00
—— A Handbook for the Electrical Laboratory and Testing Room. Two Volumes	8vo, each,	*5 00
Fleury, P. Preparation and Uses of White Zinc Paints	8vo,	*2 50
Flynn, P. J. Flow of Water. (Science Series No. 84.)	12mo,	0 50
—— Hydraulic Tables. (Science Series No. 66.)	16mo,	0 50
Forgie, J. Shield Tunneling	8vo. (*In Press.*)	
Foster, H. A. Electrical Engineers' Pocket-book. (*Seventh Edition.*)	12mo, leather,	5 00
—— Engineering Valuation of Public Utilities and Factories	8vo,	*3 00
—— Handbook of Electrical Cost Data	8vo (*In Press.*)	
Foster, Gen. J. G. Submarine Blasting in Boston (Mass.) Harbor	4to,	3 50
Fowle, F. F. Overhead Transmission Line Crossings	12mo,	*1 50
—— The Solution of Alternating Current Problems	8vo (*In Press.*)	
Fox, W. G. Transition Curves. (Science Series No. 110.)	16mo,	0 50
Fox, W., and Thomas, C. W. Practical Course in Mechanical Drawing	12mo,	1 25
Foye, J. C. Chemical Problems. (Science Series No. 69.)	16mo,	0 50
—— Handbook of Mineralogy. (Science Series No. 86.)	16mo,	0 50
Francis, J. B. Lowell Hydraulic Experiments	4to,	15 00
Franzen, H. Exercises in Gas Analysis	12mo,	*1 00
French, J. W. Machine Tools, 2 vols	4to,	*15 00
Freudemacher, P. W. Electrical Mining Installations. (Installation Manuals Series.)	12mo,	*1 00
Frith, J. Alternating Current Design	8vo,	*2 00
Fritsch, J. Manufacture of Chemical Manures. Trans. by D. Grant.	8vo,	*4 00

Frye, A. I. Civil Engineers' Pocket-book .... 12mo, leather,	*5 00
Fuller, G. W. Investigations into the Purification of the Ohio River. 4to,	*10 00
Furnell, J. Paints, Colors, Oils, and Varnishes ....8vo.	*1 00
Gairdner, J. W. I. Earthwork ....8vo (*In Press.*)	
Gant, L. W. Elements of Electric Traction 8vo,	*2 50
Garcia, A. J. R. V. Spanish-English Railway Terms 8vo,	*4 50
Garforth, W. E. Rules for Recovering Coal Mines after Explosions and Fires ....12mo, leather,	1 50
Garrard, C. C. Electric Switch and Controlling Gear....(*In Press.*)	
Gaudard, J. Foundations. (Science Series No. 34.) 16mo,	0 50
Gear, H. B., and Williams, P. F. Electric Central Station Distribution Systems 8vo,	*3 00
Geerligs, H. C. P. Cane Sugar and Its Manufacture 8vo,	*5 00
Geikie, J. Structural and Field Geology 8vo,	*4 00
—— Mountains. Their Growth, Origin and Decay 8vo,	*4 00
—— The Antiquity of Man in Europe 8vo,	*3 00
Georgi, F., and Schubert, A. Sheet Metal Working. Trans. by C. Salter......... ....8vo,	3 00
Gerber, N. Analysis of Milk, Condensed Milk, and Infants' Milk-Food. 8vo,	1 25
Gerhard, W. P. Sanitation, Watersupply and Sewage Disposal of Country Houses 12mo,	*2 00
—— Gas Lighting (Science Series No. 111.).................. 16mo,	0 50
—— Household Wastes. (Science Series No. 97.)................16mo,	0 50
—— House Drainage. (Science Series No. 63.)..................16mo,	0 50
Gerhard, W. P. Sanitary Drainage of Buildings. (Science Series No. 93.) 16mo,	0 50
Gerhardi, C. W. H. Electricity Meters 8vo,	*4 00
Geschwind, L. Manufacture of Alum and Sulphates. Trans. by C. Salter 8vo,	*5 00
Gibbs, W. E. Lighting by Acetylene 12mo,	*1 50
Gibson, A. H. Hydraulics and Its Application 8vo,	*5 00
—— Water Hammer in Hydraulic Pipe Lines 12mo,	*2 00
Gibson, A. H., and Ritchie, E. G. Circular Arc Bow Girder 4to,	*3 50
Gilbreth, F. B. Motion Study 12mo,	*2 00
—— Bricklaying System 8vo,	*3 00
—— Field System ....12mo, leather,	*3 00
—— Primer of Scientific Management 12mo,	*1 00
Gillette, H. P. Handbook of Cost Data...............12mo, leather,	*5 00
—— Rock Excavation Methods and Cost 12mo,	*3 00
—— and Dana, R. T. Cost Keeping and Management Engineering. 8vo,	*3 50
—— and Hill, C. S. Concrete Construction, Methods and Cost....8vo,	*5 00
Gillmore, Gen. Q. A. Limes, Hydraulic Cements and Mortars 8vo,	4 00
—— Roads, Streets, and Pavements 12mo,	2 00
Godfrey, E. Tables for Structural Engineers..........16mo, leather,	*2 50
Golding, H. A. The Theta-Phi Diagram.........................12mo,	*1 25
Goldschmidt, R. Alternating Current Commutator Motor 8vo,	*3 00
Goodchild, W. Precious Stones. (Westminster Series.)............8vo,	*2 00

Goodeve, T. M. Textbook on the Steam-engine	12mo,	2 00
Gore, G. Electrolytic Separation of Metals	8vo,	*3 50
Gould, E. S. Arithmetic of the Steam-engine	12mo,	1 00
—— Calculus. (Science Series No. 112.)	16mo,	0 50
—— High Masonry Dams. (Science Series No. 22.)	16mo,	0 50
—— Practical Hydrostatics and Hydrostatic Formulas. (Science Series No. 117.)	16mo,	0 50
Gratacap, L. P. A Popular Guide to Minerals	8vo,	*3 00
Gray, J. Electrical Influence Machines	12mo,	2 00
—— Marine Boiler Design	12mo,	*1 25
Greenhill, G. Dynamics of Mechanical Flight	8vo,	*2 50
Greenwood, E. Classified Guide to Technical and Commercial Books.	8vo,	*3 00
Gregorius, R. Mineral Waxes. Trans. by C. Salter	12mo,	*3 00
Griffiths, A. B. A Treatise on Manures	12mo,	3 00
—— Dental Metallurgy	8vo,	*3 50
Gross, E. Hops	8vo,	*4 50
Grossman, J. Ammonia and Its Compounds	12mo,	*1 25
Groth, L. A. Welding and Cutting Metals by Gases or Electricity. (Westminster Series)	8vo,	*2 00
Grover, F. Modern Gas and Oil Engines	8vo,	*2 00
Gruner, A. Power-loom Weaving	8vo,	*3 00
Güldner, Hugo. Internal Combustion Engines. Trans. by H. Diederichs.	4to,	*10 00
Gunther, C. O. Integration		
Gurden, R. L. Traverse Tables	folio, half morocco,	*7 50
Guy, A. E. Experiments on the Flexure of Beams	8vo,	*1 25

Haenig, A. Emery and Emery Industry	8vo,	*2 50
Hainbach, R. Pottery Decoration. Trans. by C. Salter	12mo,	*3 00
Hale, W. J. Calculations of General Chemistry	12mo,	*1 00
Hall, C. H. Chemistry of Paints and Paint Vehicles	12mo,	*2 00
Hall, G. L. Elementary Theory of Alternate Current Working	8vo,	*1 50
Hall, R. H. Governors and Governing Mechanism	12mo,	*2 00
Hall, W. S. Elements of the Differential and Integral Calculus	8vo,	*2 25
—— Descriptive Geometry	8vo volume and a 4to atlas,	*3 50
Haller, G. F., and Cunningham, E. T. The Tesla Coil	12mo,	*1 25
Halsey, F. A. Slide Valve Gears	12mo,	1 50
—— The Use of the Slide Rule. (Science Series No. 114.)	16mo,	0 50
—— Worm and Spiral Gearing. (Science Series No. 116.)	16mo,	0 50
Hamilton, W. G. Useful Information for Railway Men	16mo,	1 00
Hammer, W. J. Radium and Other Radio-active Substances	8vo,	*1 00
Hancock, H. Textbook of Mechanics and Hydrostatics	8vo,	1 50
Hancock, W. C. Refractory Materials. (Metallurgy Series.)	(*In Press.*)	
Hardy, E. Elementary Principles of Graphic Statics	12mo,	*1 50
Haring, H. Engineering Law.		
Vol. I. Law of Contract	8vo,	*4 00
Harris, S. M. Practical Topographical Surveying	(*In Press.*)	
Harrison, W. B. The Mechanics' Tool-book	12mo,	1 50
Hart, J. W. External Plumbing Work	8vo,	*3 00
—— Hints to Plumbers on Joint Wiping	8vo,	*3 00

—— Principles of Hot Water Supply	8vo,	*3 00
—— Sanitary Plumbing and Drainage	8vo,	*3 00
Haskins, C. H. The Galvanometer and Its Uses	16mo,	1 50
Hatt, J. A. H. The Colorist	square 12mo,	*1 50
Hausbrand, E. Drying by Means of Air and Steam. Trans. by A. C. Wright	12mo,	*2 00
—— Evaporating, Condensing and Cooling Apparatus. Trans. by A. C. Wright	8vo,	*5 00
Hausmann, E. Telegraph Engineering	8vo,	*3 00
Hausner, A. Manufacture of Preserved Foods and Sweetmeats. Trans. by A. Morris and H. Robson	8vo,	*3 00
Hawkesworth, J. Graphical Handbook for Reinforced Concrete Design.	4to,	*2 50
Hay, A. Alternating Currents	8vo,	*2 50
—— Electrical Distributing Networks and Distributing Lines	8vo,	*3 50
—— Continuous Current Engineering	8vo,	*2 50
Hayes, H. V. Public Utilities, Their Cost New and Depreciation	8vo,	*2 00
—— Public Utilities, Their Fair Present Value and Return	8vo,	*2 00
Heather, H. J. S. Electrical Engineering	8vo,	*3 50
Heaviside, O. Electromagnetic Theory. Vols. I and II	8vo, each,	*5 00
Vol. III	8vo,	*7 50
Heck, R. C. H. The Steam Engine and Turbine	8vo,	*3 50
—— Steam-Engine and Other Steam Motors. Two Volumes.		
Vol. I. Thermodynamics and the Mechanics	8vo,	*3 50
Vol. II. Form, Construction, and Working	8vo,	*5 00
—— Notes on Elementary Kinematics	8vo, boards,	*1 00
—— Graphics of Machine Forces	8vo, boards,	*1 00
Heermann, P. Dyers' Materials. Trans. by A. C. Wright	12mo,	*2 50
Heidenreich, E. L. Engineers' Pocketbook of Reinforced Concrete,	16mo, leather,	*3 00
Hellot, Macquer and D'Apligny. Art of Dyeing Wool, Silk and Cotton.	8vo,	*2 00
Henrici, O. Skeleton Structures	8vo,	1 50
Hering, D. W. Essentials of Physics for College Students	8vo,	*1 75
Hering-Shaw, A. Domestic Sanitation and Plumbing. Two Vols.	8vo,	*5 00
Hering-Shaw, A. Elementary Science	8vo,	*2 00
Herrmann, G. The Graphical Statics of Mechanism. Trans. by A. P. Smith	12mo,	2 00
Herzfeld, J. Testing of Yarns and Textile Fabrics	8vo,	*3 50
Hildebrandt, A. Airships, Past and Present	8vo,	*3 50
Hildenbrand, B. W. Cable-Making. (Science Series No. 32.)	16mo,	0 50
Hilditch, T. P. A Concise History of Chemistry	12mo,	*1 25
Hill, C. S. Concrete Inspection	16mo,	*1 00
Hill, J. W. The Purification of Public Water Supplies. New Edition.	(*In Press.*)	
—— Interpretation of Water Analysis	(*In Press.*)	
Hill, M. J. M. The Theory of Proportion	8vo,	*2 50
Hiroi, I. Plate Girder Construction. (Science Series No. 95.)	16mo,	0 50
—— Statically-Indeterminate Stresses	12mo,	*2 00
Hirshfeld, C. F. Engineering Thermodynamics. (Science Series No. 45.)	16mo,	0 50

Hobart, H. M. Heavy Electrical Engineering	8vo,	*4 50
—— Design of Static Transformers	12mo,	*2 00
—— Electricity	8vo,	*2 00
—— Electric Trains	8vo,	*2 50
Hobart, H. M. Electric Propulsion of Ships	8vo,	*2 00
Hobart, J. F. Hard Soldering, Soft Soldering and Brazing	12mo,	*1 00
Hobbs, W. R. P. The Arithmetic of Electrical Measurements	12mo,	0 50
Hoff, J. N. Paint and Varnish Facts and Formulas	12mo,	*1 50
Hole, W. The Distribution of Gas	8vo,	*7 50
Holley, A. L. Railway Practice	folio,	6 00
Holmes, A. B. The Electric Light Popularly Explained	12mo, paper,	0 50
Hopkins, N. M. Experimental Electrochemistry	8vo,	
—— Model Engines and Small Boats	12mo,	1 25
Hopkinson, J., Shoolbred, J. N., and Day, R. E. Dynamic Electricity. (Science Series No. 71.)	16mo,	0 50
Horner, J. Practical Ironfounding	8vo,	*2 00
—— Gear Cutting, in Theory and Practice	8vo,	*3 00
Houghton, C. E. The Elements of Mechanics of Materials	12mo,	*2 00
Houllevigue, L. The Evolution of the Sciences	8vo,	*2 00
Houstoun, R. A. Studies in Light Production	12mo,	2 00
Hovenden, F. Practical Mathematics for Young Engineers	12mo,	*1 00
Howe, G. Mathematics for the Practical Man	12mo,	*1 25
Howorth, J. Repairing and Riveting Glass, China and Earthenware.	8vo, paper,	*0 50
Hubbard, E. The Utilization of Wood-waste	8vo,	*2 00
Hübner, J. Bleaching and Dyeing of Vegetable and Fibrous Materials. (Outlines of Industrial Chemistry.)	8vo,	*5 00
Hudson, O. F. Iron and Steel. (Outlines of Industrial Chemistry.)	8vo,	*2 00
Humphrey, J. C. W. Metallography of Strain. (Metallurgy Series.)	*(In Press.)*	
Humphreys, A. C. The Business Features of Engineering Practice	8vo,	*1 25
Hunter, A. Bridge Work	8vo. *(In Press.)*	
Hurst, G. H. Handbook of the Theory of Color	8vo,	*2 50
—— Dictionary of Chemicals and Raw Products	8vo,	*3 00
—— Lubricating Oils, Fats and Greases	8vo,	*4 00
—— Soaps	8vo,	*5 00
Hurst, G. H., and Simmons, W. H. Textile Soaps and Oils	8vo,	*2 50
Hurst, H. E., and Lattey, R. T. Text-book of Physics	8vo,	*3 00
—— Also published in three parts.		
Part I. Dynamics and Heat		*1 25
Part II. Sound and Light		*1 25
Part III. Magnetism and Electricity		*1 50
Hutchinson, R. W., Jr. Long Distance Electric Power Transmission.	12mo,	*3 00
Hutchinson, R. W., Jr., and Thomas, W. A. Electricity in Mining	12mo, *(In Press.)*	
Hutchinson, W. B. Patents and How to Make Money Out of Them.	12mo,	1 25
Hutton, W. S. Steam-boiler Construction	8vo,	6 00
—— The Works' Manager's Handbook	8vo,	6 00

Hyde, E. W. Skew Arches. (Science Series No. 15.)..........16mo, 0 50
Hyde, F. S. Solvents, Oils, Gums, Waxes......................8vo, *2 00

Induction Coils. (Science Series No. 53.).....................16mo, 0 50
Ingham, A. E. Gearing. A practical treatise....................8vo, *2 50
Ingle, H. Manual of Agricultural Chemistry....................8vo, *3 00
Inness, C. H. Problems in Machine Design......................12mo, *2 00
—— Air Compressors and Blowing Engines.....................12mo, *2 00
—— Centrifugal Pumps...12mo, *2 00
—— The Fan...12mo, *2 00
Isherwood, B. F. Engineering Precedents for Steam Machinery...8vo, 2 50
Ivatts, E. B. Railway Management at Stations.................8vo, *2 50

Jacob, A., and Gould, E. S. On the Designing and Construction of Storage Reservoirs. (Science Series No. 6)............16mo, 0 50
Jannettaz, E. Guide to the Determination of Rocks. Trans. by G. W. Plympton..12mo, 1 50
Jehl, F. Manufacture of Carbons..............................8vo, *4 00
Jennings, A. S. Commercial Paints and Painting. (Westminster Series.) 8vo, *2 00
Jennison, F. H. The Manufacture of Lake Pigments............8vo, *3 00
Jepson, G. Cams and the Principles of their Construction........8vo, *1 50
—— Mechanical Drawing......................8vo (*In Preparation.*)
Jervis-Smith, F. J. Dynamometers..............................8vo, *3 50
Jockin, W. Arithmetic of the Gold and Silversmith............12mo, *1 00
Johnson, J. H. Arc Lamps and Accessory Apparatus. (Installation Manuals Series.)....................................12mo, *0 75
Johnson, T. M. Ship Wiring and Fitting. (Installation Manuals Series.) 12mo, *0 75
Johnson, W. McA. The Metallurgy of Nickel...... (*In Preparation.*)
Johnston, J. F. W., and Cameron, C. Elements of Agricultural Chemistry and Geology.......................................12mo, 2 60
Joly, J. Radioactivity and Geology...........................12mo, *3 00
Jones, H. C. Electrical Nature of Matter and Radioactivity 12mo, *2 00
—— Evolution of Solutions..........................(*In Press.*)
—— New Era in Chemistry.......................................12mo, *2 00
Jones, J. H. Tinplate Industry...................................8vo, *3 00
Jones, M. W. Testing Raw Materials Used in Paint...........12mo, *2 00
Jordan, L. C. Practical Railway Spiral................12mo, leather, *1 50
Joynson, F. H. Designing and Construction of Machine Gearing ..8vo, 2 00
Jüptner, H. F. V. Siderology: The Science of Iron..............8vo, *5 00

Kansas City Bridge...4to, 6 00
Kapp, G. Alternate Current Machinery. (Science Series No. 96.).16mo, 0 50
Keim, A. W. Prevention of Dampness in Buildings..............8vo, *2 00
Keller, S. S. Mathematics for Engineering Students. 12mo, half leather.
Algebra and Trigonometry, with a Chapter on Vectors........... *1 75
Plane and Solid Geometry..................................... *1.25
—— and Knox, W. E. Analytical Geometry and Calculus........... *2 00
Kelsey, W. R. Continuous-current Dynamos and Motors........8vo, *2 50

Kemble, W. T., and Underhill, C. R. The Periodic Law and the Hydrogen Spectrum	8vo, paper,	*0 50
Kemp, J. F. Handbook of Rocks	8vo,	*1 50
Kendall, E. Twelve Figure Cipher Code	4to,	*12 50
Kennedy, A. B. W., and Thurston, R. H. Kinematics of Machinery. (Science Series No. 54.)	16mo,	0 50
Kennedy, A. B. W., Unwin, W. C., and Idell, F. E. Compressed Air. (Science Series No. 106.)	16mo,	0 50
Kennedy, R. Modern Engines and Power Generators. Six Volumes.	4to,	15 00
Single Volumes	each,	3 00
—— Electrical Installations. Five Volumes	4to,	15 00
Single Volumes	each,	3 50
—— Flying Machines; Practice and Design	12mo,	*2 00
—— Principles of Aeroplane Construction	8vo,	*1 50
Kennelly, A. E. Electro-dynamic Machinery	8vo,	1 50
Kent, W. Strength of Materials. (Science Series No. 41.)	16mo,	0 50
Kershaw, J. B. C. Fuel, Water and Gas Analysis	8vo,	*2 50
—— Electrometallurgy. (Westminster Series.)	8vo,	*2 00
—— The Electric Furnace in Iron and Steel Production	12mo,	*1 50
—— Electro-Thermal Methods of Iron and Steel Production	8vo,	*3 00
Kindelan, J. Trackman's Helper	12mo,	*1 50
Kinzbrunner, C. Alternate Current Windings	8vo,	*1 50
—— Continuous Current Armatures	8vo,	*1 50
—— Testing of Alternating Current Machines	8vo,	*2 00
Kirkaldy, W. G. David Kirkaldy's System of Mechanical Testing	4to,	10 00
Kirkbride, J. Engraving for Illustration	8vo,	*1 50
Kirkham, J. E. Structural Engineering	8vo,	*5 00
Kirkwood, J. P. Filtration of River Waters	4to,	7 50
Kirschke, A. Gas and Oil Engines	12mo,	*1 25
Klein, J. F. Design of a High-speed Steam-engine	8vo,	*5 00
—— Physical Significance of Entropy	8vo,	*1 50
Kleinhans, F. B. Boiler Construction	8vo,	3 00
Knight, R.-Adm. A. M. Modern Seamanship	8vo,	*7 50
Half morocco		*9 00
Knott, C. G., and Mackay, J. S. Practical Mathematics	8vo,	2 00
Knox, J. Physico-Chemical Calculations	12mo,	*1 00
—— Fixation of Atmospheric Nitrogen. (Chemical Monographs.)	12mo,	*0 75
Koester, F. Steam-Electric Power Plants	4to,	*5 00
—— Hydroelectric Developments and Engineering	4to,	*5 00
Koller, T. The Utilization of Waste Products	8vo,	*3 00
—— Cosmetics	8vo,	*2 50
Kremann, R. Application of the Physico-Chemical Theory to Technical Processes and Manufacturing Methods. Trans. by H. E. Potts	8vo,	*2 50
Kretchmar, K. Yarn and Warp Sizing	8vo,	*4 00
Lallier, E. V. Elementary Manual of the Steam Engine	12mo,	*2 00
Lambert, T. Lead and Its Compounds	8vo,	*3 50
—— Bone Products and Manures	8vo,	*3 50

Lamborn, L. L. Cottonseed Products	8vo,	*3 00
—— Modern Soaps, Candles, and Glycerin	8vo,	*7 50
Lamprecht, R. Recovery Work After Pit Fires. Trans. by C. Salter	8vo,	*4 00
Lancaster, M. Electric Cooking, Heating and Cleaning	8vo,	*1 50
Lanchester, F. W. Aerial Flight. Two Volumes. 8vo.		
Vol. I. Aerodynamics		*6 00
—— Aerial Flight. Vol. II. Aerodonetics		*6.00
Lange, K. R. By-Products of Coal-Gas Manufacture	12mo,	2 00
Larner, E. T. Principles of Alternating Currents	12mo.	*1 25
La Rue, B. F. Swing Bridges. (Science Series No. 107.)	16mo,	0 50
Lassar-Cohn. Dr. Modern Scientific Chemistry. Trans. by M. M. Pattison Muir	12mo,	*2 00
Latimer, L. H., Field, C. J., and Howell, J. W. Incandescent Electric Lighting. (Science Series No. 57.)	16mo,	0 50
Latta, M. N. Handbook of American Gas-Engineering Practice	8vo,	*4 50
—— American Producer Gas Practice	4to,	*6 00
Laws, B. C. Stability and Equilibrium of Floating Bodies	8vo,	*3 50
Lawson, W. R. British Railways. A Financial and Commercial Survey	8vo,	2 00
Leask, A. R. Breakdowns at Sea	12mo,	2 00
—— Refrigerating Machinery	12mo,	2 00
Lecky, S. T. S. " Wrinkles " in Practical Navigation	8vo,	*8 00
Le Doux, M. Ice-Making Machines. (Science Series No. 46.)	16mo,	0 50
Leeds, C. C. Mechanical Drawing for Trade Schools. (Machinery Trades Edition.)	oblong 4to	*2 00
—— Mechanical Drawing for High and Vocational Schools	4to,	*1 50
Lefévre, L. Architectural Pottery. Trans. by H. K. Bird and W. M. Binns	4to,	*7 50
Lehner, S. Ink Manufacture. Trans. by A. Morris and H. Robson	8vo,	*2 50
Lemstrom, S. Electricity in Agriculture and Horticulture	8vo,	*1 50
Letts, E. A. Fundamental Problems in Chemistry	8vo,	*2 00
Le Van, W. B. Steam-Engine Indicator. (Science Series No. 78.)	16mo,	0 50
Lewes, V. B. Liquid and Gaseous Fuels. (Westminster Series.)	8vo,	*2 00
—— Carbonization of Coal	8vo,	*3 00
Lewis, L. P. Railway Signal Engineering	8vo,	*3 50
Lieber, B. F. Lieber's Standard Telegraphic Code	8vo,	*10 00
—— Code. German Edition	8vo,	*10 00
—— —— Spanish Edition	8vo,	*10 00
—— —— French Edition	8vo,	*10 00
—— Terminal Index	8vo,	*2 50
—— Lieber's Appendix	folio,	*15 00
—— —— Handy Tables	4to,	*2 50
—— Bankers and Stockbrokers' Code and Merchants and Shippers' Blank Tables	8vo,	*15 00
—— 100,000,000 Combination Code	8vo,	*10 00
—— Engineering Code	8vo,	*12 50
Livermore, V. P., and Williams, J. How to Become a Competent Motorman	12mo,	*1 00
Livingstone, R. Design and Construction of Commutators	8vo,	*2 25
—— Mechanical Design and Construction of Generators	8vo,	*3 50
Lobben, P. Machinists' and Draftsmen's Handbook	8vo,	2 50

Lockwood, T. D. Electricity, Magnetism, and Electro-telegraph....8vo,	2 50
Lockwood, T. D. Electrical Measurement and the Galvanometer. 12mo,	0 75
Lodge, O. J. Elementary Mechanics....12mo,	1 50
—— Signalling Across Space without Wires....8vo,	*2 00
Loewenstein, L. C., and Crissey, C. P. Centrifugal Pumps....	*4 50
Lomax, J. W. Cotton Spinning....12mo,	1 50
Lord, R. T. Decorative and Fancy Fabrics....8vo,	*3 50
Loring, A. E. A Handbook of the Electromagnetic Telegraph....16mo	0 50
—— Handbook. (Science Series No. 39.)....16m,	0 50
Lovell, D. H. Practical Switchwork....12mo,	*1 00
Low, D. A. Applied Mechanics (Elementary)....16mo,	0 80
Lubschez, B. J. Perspective....12mo,	*1 50
Lucke, C. E. Gas Engine Design....8vo,	*3 00
—— Power Plants: Design, Efficiency, and Power Costs. 2 vols. (*In Preparation.*)	
Luckiesh, M. Color and Its Application....8vo,	*3 00
Lunge, G. Coal-tar and Ammonia. Three Volumes....	*18 00
—— Technical Gas Analysis....8vo,	*4 00
—— Manufacture of Sulphuric Acid and Alkali. Four Volumes....8vo,	
Vol. I. Sulphuric Acid. In three parts....	*18 00
Vol. II. Salt Cake, Hydrochloric Acid and Leblanc Soda. In two parts....	*15.00
Vol. III. Ammonia Soda....	*10 00
Vol. IV. Electrolytic Methods....(*In Press.*)	
—— Technical Chemists' Handbook....12mo, leather,	*3 50
—— Technical Methods of Chemical Analysis. Trans. by C. A. Keane in collaboration with the corps of specialists.	
Vol. I. In two parts....8vo,	*15 00
Vol. II. In two parts....8vo,	*18 00
Vol. III. In two parts....8vo,	*18 00
The set (3 vols.) complete....	*48 00
Luquer, L. M. Minerals in Rock Sections....8vo,	*1 50
Macaulay, J., and Hall, C. Modern Railway Working, 8 vols....4to,	20 00
Each volume separately....	3 00
Macewen, H. A. Food Inspection....8vo,	*2 50
Mackenzie, N. F. Notes on Irrigation Works....8vo,	*2 50
Mackie, J. How to Make a Woolen Mill Pay....8vo,	*2 00
Mackrow, C. Naval Architect's and Shipbuilder's Pocket-book. 16mo, leather,	5 00
Maguire, Wm. R. Domestic Sanitary Drainage and Plumbing....8vo,	4 00
Malcolm, C. W. Textbook on Graphic Statics....8vo,	*3 00
Malcolm, H. W. Submarine Telegraph Cable....(*In Press.*)	
Mallet, A. Compound Engines. Trans. by R. R. Buel. (Science Series No. 10.)....16mo,	
Mansfield, A. N. Electro-magnets. (Science Series No. 64.)....16mo,	0 50
Marks, E. C. R. Construction of Cranes and Lifting Machinery....12mo,	*1 50
—— Construction and Working of Pumps....12mo,	*1 50

—— Manufacture of Iron and Steel Tubes	12mo,	*2 00
—— Mechanical Engineering Materials	12mo,	*1 00
Marks, G. C. Hydraulic Power Engineering	8vo,	3 50
—— Inventions, Patents and Designs	12mo,	*1 00
Marlow, T. G. Drying Machinery and Practice	8vo,	*5 00
Marsh, C. F. Concise Treatise on Reinforced Concrete	8vo,	*2 50
—— Reinforced Concrete Compression Member Diagram. Mounted on Cloth Boards		*1.50
Marsh, C. F., and Dunn, W. Manual of Reinforced Concrete and Concrete Block Construction	16mo, morocco,	*2 50
Marshall, W. J., and Sankey, H. R. Gas Engines. (Westminster Series.)	8vo,	*2 00
Martin, G. Triumphs and Wonders of Modern Chemistry	8vo,	*2 00
—— Modern Chemistry and Its Wonders	8vo,	*2 00
Martin, N. Properties and Design of Reinforced Concrete	12mo,	*2 50
Martin, W. D. Hints to Engineers	12mo,	*1 00
Massie, W. W., and Underhill, C. R. Wireless Telegraphy and Telephony.	12mo,	*1 00
Matheson, D. Australian Saw-Miller's Log and Timber Ready Reckoner.	12mo, leather,	1 50
Mathot, R. E. Internal Combustion Engines	8vo,	*6 00
Maurice, W. Electric Blasting Apparatus and Explosives	8vo,	*3 50
—— Shot Firer's Guide	8vo,	*1 50
Maxwell, J. C. Matter and Motion. (Science Series No. 36.).	16mc,	0 50
Maxwell, W. H., and Brown, J. T. Encyclopedia of Municipal and Sanitary Engineering	4to,	*10 00
Mayer, A. M. Lecture Notes on Physics	8vo,	2 00
Mayer, C., and Slippy, J. C. Telephone Line Construction	8vo,	*3 00
McCullough, E. Practical Surveying	12mo,	*2 00
—— Engineering Work in Cities and Towns	8vo,	*3 00
—— Reinforced Concrete	12mo,	*1 50
McCullough, R. S. Mechanical Theory of Heat	8vo,	3 50
McGibbon, W. C. Indicator Diagrams for Marine Engineers	8vo,	*3 00
—— Marine Engineers' Drawing Book	oblong 4to,	*2 00
McIntosh, J. G. Technology of Sugar	8vo,	*5 00
—— Industrial Alcohol	8vo,	*3 00
—— Manufacture of Varnishes and Kindred Industries. Three Volumes. 8vo.		
Vol. I. Oil Crushing, Refining and Boiling		*3 50
Vol. II. Varnish Materials and Oil Varnish Making		*4 00
Vol. III. Spirit Varnishes and Materials		*4 50
McKnight, J. D., and Brown, A. W. Marine Multitubular Boilers		*1 50
McMaster, J. B. Bridge and Tunnel Centres. (Science Series No. 20.)	16mo,	0 50
McMechen, F. L. Tests for Ores, Minerals and Metals	12mo,	*1 00
McPherson, J. A. Water-works Distribution	8vo,	2 50
Meade, R. K. Design and Equipment of Small Chemical Laboratories,	8vo,	
Melick, C. W. Dairy Laboratory Guide	12mo,	*1 25

Mensch, L. J. Reinforced Concrete Pocket Book	16mo, leather,	*4 00
Merck, E. Chemical Reagents; Their Purity and Tests. Trans. by H. E. Schenck	8vo,	1 00
Merivale, J. H. Notes and Formulae for Mining Students	12mo,	1 50
Merritt, Wm. H. Field Testing for Gold and Silver	16mo, leather,	1 50
Meyer, J. G. A., and Pecker, C. G. Mechanical Drawing and Machine Design	4to,	5 00
Mierzinski, S. Waterproofing of Fabrics. Trans. by A. Morris and H. Robson	8vo,	*2 50
Miessner, B. F. Radio Dynamics	*(In Press.)*	
Miller, G. A. Determinants. (Science Series No 105.)	16mo,	
Milroy, M. E. W. Home Lace-making	12mo,	*1 00
Mitchell, C. A. Mineral and Aerated Waters	8vo,	*3 00
Mitchell, C. A., and Prideaux, R. M. Fibres Used in Textile and Allied Industries	8vo,	*3 00
Mitchell, C. F., and G. A. Building Construction and Drawing.	12mo.	
Elementary Course		*1 50
Advanced Course		*2 50
Monckton, C. C. F. Radiotelegraphy. (Westminster Series.)	8vo,	*2 00
Monteverde, R. D. Vest Pocket Glossary of English-Spanish, Spanish-English Technical Terms	64mo, leather,	*1 00
Montgomery, J. H. Electric Wiring Specifications	16mo,	*1 00
Moore, E. C. S. New Tables for the Complete Solution of Ganguillet and Kutter's Formula	8vo,	*5 00
Morecroft, J. H., and Hehre, F. W. Short Course in Electrical Testing.	8vo,	*1 50
Morgan, A. P. Wireless Telegraph Apparatus for Amateurs	12mo,	*1 50
Moses, A. J. The Characters of Crystals	8vo,	*2 00
—— and Parsons, C. L. Elements of Mineralogy	8vo,	*2 50
Moss, S.A. Elements of Gas Engine Design. (Science Series No. 121.)	16mo,	0 50
—— The Lay-out of Corliss Valve Gears. (Science Series No. 119.)	16mo,	0 50
Mulford, A. C. Boundaries and Landmarks	12mo,	*1 00
Mullin, J. P. Modern Moulding and Pattern-making	12mo,	2 50
Munby, A. E. Chemistry and Physics of Building Materials. (Westminster Series.)	8vo,	*2 00
Murphy, J. G. Practical Mining	16mo,	1 00
Murphy, W. S. Textile Industries. Eight Volumes		*20 00
Sold separately, each,		*3 00
Murray, J. A. Soils and Manures. (Westminster Series.)	8vo,	*2 00
Naquet, A. Legal Chemistry	12mo,	2 00
Nasmith, J. The Student's Cotton Spinning	8vo,	3 00
—— Recent Cotton Mill Construction	12mo,	2 00
Neave, G. B., and Heilbron, I. M. Identification of Organic Compounds.	12mo,	*1 25
Neilson, R. M. Aeroplane Patents	8vo,	*2 00
Nerz, F. Searchlights. Trans. by C. Rodgers	8vo,	*3 00
Neuberger, H., and Noalhat, H. Technology of Petroleum. Trans. by J. G. McIntosh	8vo,	*10 00
Newall, J. W. Drawing, Sizing and Cutting Bevel-gears	8vo,	1 50

Newbeging, T. Handbook for Gas Engineers and Managers......8vo, *6 50
Newton, G. J. Underground Distribution Systems........(*In Press.*)
Nicol, G. Ship Construction and Calculations..................8vo, *4 50
Nipher, F. E. Theory of Magnetic Measurements.............12mo, 1 00
Nisbet, H. Grammar of Textile Design.......................8vo, *3 00
Nolan, H. The Telescope. (Science Series No. 51.)...........16mo, 0 50
Noll, A. How to Wire Buildings..............................12mo, 1 50
North, H. B. Laboratory Experiments in General Chemistry.....12mo, *1 00
Nugent, E. Treatise on Optics...............................12mo, 1 50

O'Connor, H. The Gas Engineer's Pocketbook..........12mo, leather, 3 50
—— Petrol Air Gas.................................12mo, *0 75
Ohm, G. S., and Lockwood, T. D. Galvanic Circuit. Translated by William Francis. (Science Series No. 102.)...........16mo, 0 50
Olsen, J. C. Text-book of Quantitative Chemical Analysis........8vo, *4 00
Olsson, A. Motor Control, in Turret Turning and Gun Elevating. (U. S. Navy Electrical Series, No. 1.)................12mo, paper, *0 50
Ormsby, M. T. M. Surveying..................................12mo, 1 50
Oudin, M. A. Standard Polyphase Apparatus and Systems........8vo, *3 00
Owen, D. Recent Physical Research...........................8vo, *1 50

Pakes, W. C. C., and Nankivell, A. T. The Science of Hygiene ..8vo, *1 75
Palaz, A. Industrial Photometry. Trans. by G. W. Patterson, Jr..8vo, *4 00
Pamely, C. Colliery Manager's Handbook.......................8vo, *10 00
Parker, P. A. M. The Control of Water.......................8vo, *5 00
Parr, G. D. A. Electrical Engineering Measuring Instruments....8vo, *3 50
Parry, E. J. Chemistry of Essential Oils and Artificial Perfumes...8vo, *5 00
—— Foods and Drugs. Two Volumes...........................8vo,
  Vol. I. Chemical and Microscopical Analysis of Foods and Drugs. *7 50
  Vol. II. Sale of Food and Drugs Act.............................. *3 00
—— and Coste, J. H. Chemistry of Pigments.................8vo, *4 50
Parry, L. Notes on Alloys...................................8vo, *3 00
—— Metalliferous Wastes 8vo, *2 00
—— Analysis of Ashes and Alloys...........................8vo, *2 00
Parry, L. A. Risk and Dangers of Various Occupations............8vo, *3 00
Parshall, H. F., and Hobart, H. M. Armature Windings............4to, *7 50
—— Electric Railway Engineering...........................4to, *10 00
Parsons, J. L. Land Drainage.................................8vo, *1 50
Parsons, S. J. Malleable Cast Iron...........................8vo, *2 50
Partington, J. R. Higher Mathematics for Chemical Students..12mo, *2 00
—— Textbook of Thermodynamics.............................8vo, *4 00
Passmore, A. C. Technical Terms Used in Architecture............8vo, *3 50
Patchell, W. H. Electric Power in Mines........................8vo, *4 00
Paterson, G. W. L. Wiring Calculations......................12mo, *2 00
—— Electric Mine Signalling Installations....................12mo, *1 50
Patterson, D. The Color Printing of Carpet Yarns...............8vo, *3 50
—— Color Matching on Textiles.............................8vo, *3 00
—— Textile Color Mixing...................................8vo, *3 00
Paulding, C. P. Condensation of Steam in Covered and Bare Pipes ..8vo, *2 00
—— Transmission of Heat through Cold-storage Insulation......12mo, *1 00

Payne, D. W. Iron Founders' Handbook	*(In Press.)*	
Peckham, S. F. Solid Bitumens	8vo,	*5 00
Peddie, R. A. Engineering and Metallurgical Books	12mo,	*1 50
Peirce, B. System of Analytic Mechanics	4to,	10 00
Pendred, V. The Railway Locomotive. (Westminster Series.)	8vo,	*2 00
Perkin, F. M. Practical Methods of Inorganic Chemistry	12mo,	*1 00
—— and Jaggers, E. M. Elementary Chemistry	12mo,	*1 00
Perrigo, O. E. Change Gear Devices	8vo,	1 00
Perrine, F. A. C. Conductors for Electrical Distribution	8vo,	*3 50
Petit, G. White Lead and Zinc White Paints	8vo,	*1 50
Petit, R. How to Build an Aeroplane. Trans. by T. O'B. Hubbard, and J. H. Ledeboer	8vo,	*1 50
Pettit, Lieut. J. S. Graphic Processes. (Science Series No. 76.)	16mo,	0 50
Philbrick, P. H. Beams and Girders. (Science Series No. 88.)	16mo,	
Phillips, J. Gold Assaying	8vo,	*2 50
—— Dangerous Goods	8vo,	3 50
Phin, J. Seven Follies of Science	12mo,	*1 25
Pickworth, C. N. The Indicator Handbook. Two Volumes	12mo, each,	1 50
—— Logarithms for Beginners	12mo, boards,	0 50
—— The Slide Rule	12mo,	1 00
Plattner's Manual of Blow-pipe Analysis. Eighth Edition, revised. Trans. by H. B. Cornwall	8vo,	*4 00
Plympton, G. W. The Aneroid Barometer. (Science Series No. 35.)	16mo,	0 50
—— How to become an Engineer. (Science Series No. 100.)	16mo,	0 50
—— Van Nostrand's Table Book. (Science Series No. 104.)	16mo,	0 50
Pochet, M. L. Steam Injectors. Translated from the French. (Science Series No. 29.)	16mo,	0 50
Pocket Logarithms to Four Places. (Science Series No. 65.)	16mo,	0 50
	leather,	1 00
Polleyn, F. Dressings and Finishings for Textile Fabrics	8vo,	*3 00
Pope, F. G. Organic Chemistry	12mo,	*2 25
Pope, F. L. Modern Practice of the Electric Telegraph	8vo,	1 50
Popplewell, W. C. Prevention of Smoke	8vo,	*3 50
—— Strength of Materials	8vo,	*1 75
Porritt, B. D. The Chemistry of Rubber. (Chemical Monographs, No. 3.)	12mo,	*0 75
Porter, J. R. Helicopter Flying Machine	12mo,	*1 25
Potts, H. E. Chemistry of the Rubber Industry. (Outlines of Industrial Chemistry)	8vo,	*2 00
Practical Compounding of Oils, Tallow and Grease	8vo,	*3 50
Pratt, K. Boiler Draught	12mo,	*1 25
—— High Speed Steam Engines	8vo,	*2 00
Pray, T., Jr. Twenty Years with the Indicator	8vo,	2 50
—— Steam Tables and Engine Constant	8vo,	2 00
Prelini, C. Earth and Rock Excavation	8vo,	*3 00
—— Graphical Determination of Earth Slopes	8vo,	*2 00
—— Tunneling. New Edition	8vo,	*3 00
—— Dredging. A Practical Treatise	8vo,	*3 00
Prescott, A. B. Organic Analysis	8vo,	5 00
Prescott, A. B., and Johnson, O. C. Qualitative Chemical Analysis	8vo,	*3 50

Prescott, A. B., and Sullivan, E. C. First Book in Qualitative Chemistry. 12mo, *1 50

Prideaux, E. B. R. Problems in Physical Chemistry..............8vo, *2 00

Primrose, G. S. C. Zinc. (Metallurgy Series.)..........(*In Press.*)

Pullen, W. W. F. Application of Graphic Methods to the Design of Structures..........12mo, *2 50

—— Injectors: Theory, Construction and Working..........12mo, *1 50

—— Indicator Diagrams..........8vo, *2 50

—— Engine Testing..........8vo, *4 50

Pulsifer, W. H. Notes for a History of Lead..........8vo, 4 00

Putsch, A. Gas and Coal-dust Firing..........8vo, *3 00

Pynchon, T. R. Introduction to Chemical Physics..........8vo, 3 00

Rafter G. W. Mechanics of Ventilation. (Science Series No. 33.). 16mo, 0 50

—— Potable Water. (Science Series No. 103.)..........16mo, 0 50

—— Treatment of Septic Sewage. (Science Series No. 118.)...16mo, 0 50

Rafter, G. W., and Baker, M. N. Sewage Disposal in the United States. 4to, *6 00

Raikes, H. P. Sewage Disposal Works..........8vo, *4 00

Randall, P. M. Quartz Operator's Handbook..........12mo, 2 00

Randau, P. Enamels and Enamelling..........8vo, *4 00

Rankine, W. J. M. Applied Mechanics..........8vo, 5 00

—— Civil Engineering..........8vo, 6 50

—— Machinery and Millwork..........8vo, 5 00

—— The Steam-engine and Other Prime Movers..........8vo, 5 00

Rankine, W. J. M., and Bamber, E. F. A Mechanical Text-book....8vo, 3 50

Raphael, F. C. Localization of Faults in Electric Light and Power Mains. 8vo, *3 00

Rasch, E. Electric Arc Phenomena. Trans. by K. Tornberg.......8vo, *2 00

Rathbone, R. L. B. Simple Jewellery..........8vo, *2 00

Rateau, A. Flow of Steam through Nozzles and Orifices. Trans. by H. B. Brydon..........8vo *1 50

Rausenberger, F. The Theory of the Recoil of Guns..........8vo, *4 50

Rautenstrauch, W. Notes on the Elements of Machine Design. 8vo, boards, *1 50

Rautenstrauch, W., and Williams, J. T. Machine Drafting and Empirical Design.

Part I. Machine Drafting..........8vo, *1 25

Part II. Empirical Design..........(*In Preparation.*)

Raymond, E. B. Alternating Current Engineering..........12mo, *2 50

Rayner, H. Silk Throwing and Waste Silk Spinning..........8vo, *2 50

Recipes for the Color, Paint, Varnish, Oil, Soap and Drysaltery Trades. 8vo, *3 50

Recipes for Flint Glass Making..........12mo, *4 50

Redfern, J. B., and Savin, J. Bells, Telephones (Installation Manuals Series.)..........16mo, *0 50

Redgrove, H. S. Experimental Mensuration..........12mo, *1 25

Redwood, B. Petroleum. (Science Series No. 92.)..........16mo, 0 50

Reed, S. Turbines Applied to Marine Propulsion.......... *5 00

Reed's Engineers' Handbook..........8vo, *5 00

—— Key to the Nineteenth Edition of Reed's Engineers' Handbook..8vo, *3 00

—— Useful Hints to Sea-going Engineers..........12mo, 1 50

—— Guide to the Use of the Slide Valve..........12mo, *1 60

Reid, E. E. Introduction to Research in Organic Chemistry. (*In Press.*)	
Reid, H. A. Concrete and Reinforced Concrete Construction 8vo,	*5 00
Reinhardt, C. W. Lettering for Draftsmen, Engineers, and Students. oblong 4to, boards,	1 00
—— The Technic of Mechanical Drafting .... oblong 4to, boards,	*1 00
Reiser, F. Hardening and Tempering of Steel. Trans. by A. Morris and H. Robson 12mo,	*2 50
Reiser, N. Faults in the Manufacture of Woolen Goods. Trans. by A. Morris and H. Robson 8vo,	*2 50
—— Spinning and Weaving Calculations 8vo,	*5 00
Renwick, W. G. Marble and Marble Working 8vo,	5 00
Reuleaux, F. The Constructor. Trans. by H. H. Suplee 4to,	*4 00
Reuterdahl, A. Theory and Design of Reinforced Concrete Arches. 8vo,	*2 00
Reynolds, O., and Idell, F. E. Triple Expansion Engines. (Science Series No. 99.) 16mo,	0 50
Rhead, G. F. Simple Structural Woodwork 12mo,	*1 00
Rhodes, H. J. Art of Lithography 8vo,	3 50
Rice, J. M., and Johnson, W. W. A New Method of Obtaining the Differential of Functions 12mo,	0 50
Richards, W. A. Forging of Iron and Steel 12mo,	*1 50
Richards, W. A., and North, H. B. Manual of Cement Testing 12mo,	*1 50
Richardson, J. The Modern Steam Engine 8vo,	*3 50
Richardson, S. S. Magnetism and Electricity 12mo,	*2 00
Rideal, S. Glue and Glue Testing 8vo,	*4 00
Rimmer, E. J. Boiler Explosions, Collapses and Mishaps 8vo,	*1 75
Rings, F. Concrete in Theory and Practice 12mo,	*2 50
—— Reinforced Concrete Bridges 4to,	*5 00
Ripper, W. Course of Instruction in Machine Drawing .... folio,	*6 00
Roberts, F. C. Figure of the Earth. (Science Series No. 79.) 16mo,	0 50
Roberts, J., Jr. Laboratory Work in Electrical Engineering 8vo,	*2 00
Robertson, L. S. Water-tube Boilers 8vo,	2 00
Robinson, J. B. Architectural Composition 8vo,	*2 50
Robinson, S. W. Practical Treatise on the Teeth of Wheels. (Science Series No. 24.) 16mo,	0 50
—— Railroad Economics. (Science Series No. 59.) 16mo,	0 50
—— Wrought Iron Bridge Members. (Science Series No. 60.) 16mo,	0 50
Robson, J. H. Machine Drawing and Sketching 8vo,	*1 50
Roebling, J. A. Long and Short Span Railway Bridges .... folio,	25 00
Rogers, A. A Laboratory Guide of Industrial Chemistry 12mo,	*1 50
Rogers, A. Industrial Chemistry 8vo,	*5 00
Rogers, F. Magnetism of Iron Vessels. (Science Series No. 30.) . 16mo,	0 50
Rohland, P. Colloidal and Crystalloidal State of Matter. Trans. by W. J. Britland and H. E. Potts 12mo,	*1 25
Rollins, W. Notes on X-Light 8vo,	*5 00
Rollinson, C. Alphabets .... Oblong, 12mo,	*1 00
Rose, J. The Pattern-makers' Assistant 8vo,	2 50
—— Key to Engines and Engine-running 12mo,	2 50
Rose, T. K. The Precious Metals. (Westminster Series.) 8vo,	*2 00
Rosenhain, W. Glass Manufacture. (Westminster Series.) 8vo,	*2 00
—— Physical Metallurgy, An Introduction to. (Metallurgy Series.) 8vo, (*In Press.*)	

Ross, W. A. Blowpipe in Chemistry and Metallurgy	12mo,	*2 00
Roth. Physical Chemistry	8vo,	*2 00
Rothery, G. C., and Edmonds, H. O. The Modern Laundry, 2 vols.,	4to, half leather,	*12 00
Rouillion, L. The Economics of Manual Training	8vo,	2 00
Rowan, F. J. Practical Physics of the Modern Steam-boiler	8vo,	*3 00
—— and Idell, F. E. Boiler Incrustation and Corrosion. (Science Series No. 27.)	16mo,	0 50
Roxburgh, W. General Foundry Practice. (Westminster Series.)	8vo,	*2 00
Ruhmer, E. Wireless Telephony. Trans. by J. Erskine-Murray	8vo,	*3 50
Russell, A. Theory of Electric Cables and Networks	8vo,	*3 00
Sabine, R. History and Progress of the Electric Telegraph	12mo,	1 25
Sanford, P. G. Nitro-explosives	8vo,	*4 00
Saunders, C. H. Handbook of Practical Mechanics	16mo,	1 00
	leather,	1 25
Sayers, H. M. Brakes for Tram Cars	8vo,	*1 25
Scheele, C. W. Chemical Essays	8vo,	*2 00
Scheithauer, W. Shale Oils and Tars	8vo,	*3 50
Schellen, H. Magneto-electric and Dynamo-electric Machines	8vo,	5 00
Scherer, R. Casein. Trans. by C. Salter	8vo,	*3 00
Schidrowitz, P. Rubber, Its Production and Industrial Uses	8vo,	*5 00
Schindler, K. Iron and Steel Construction Works.	12mo,	*1 25
Schmall, C. N. First Course in Analytic Geometry, Plane and Solid.	12mo, half leather,	*1 75
Schmall, C. N., and Shack, S. M. Elements of Plane Geometry	12mo,	*1 25
Schmeer, L. Flow of Water	8vo,	*3 00
Schumann, F. A Manual of Heating and Ventilation	12mo, leather,	1 50
Schwarz, E. H. L. Causal Geology	8vo,	*2 50
Schweizer, V. Distillation of Resins	8vo,	*3 50
Scott, W. W. Qualitative Analysis. A Laboratory Manual	8vo,	*1 50
Scribner, J. M. Engineers' and Mechanics' Companion	16mo, leather,	1 50
Scudder, H. Electrical Conductivity and Ionization Constants of Organic Compounds	8vo,	*3 00
Searle, A. B. Modern Brickmaking	8vo,	*5 00
—— Cement, Concrete and Bricks	8vo,	*3 00
Searle, G. M. "Sumners' Method." Condensed and Improved. (Science Series No. 124.)	16mo,	0 50
Seaton, A. E. Manual of Marine Engineering	8vo	8 00
Seaton, A. E., and Rounthwaite, H. M. Pocket-book of Marine Engineering	16mo, leather,	3 50
Seeligmann, T., Torrilhon, G. L., and Falconnet, H. India Rubber and Gutta Percha. Trans. by J. G. McIntosh	8vo,	*5 00
Seidell, A. Solubilities of Inorganic and Organic Substances	8vo,	*3 00
Seligman, R. Aluminum. (Metallurgy Series.)	*(In Press.)*	
Sellew, W. H. Steel Rails	4to,	*12 50
—— Railway Maintenance	12mo,	*2 50
Senter, G. Outlines of Physical Chemistry	12mo,	*1 75
—— Text-book of Inorganic Chemistry	12mo,	*1 75

Sever, G. F. Electric Engineering Experiments	8vo, boards,	*1 00
Sever, G. F., and Townsend, F. Laboratory and Factory Tests in Electrical Engineering	8vo,	*2 50
Sewall, C. H. Wireless Telegraphy	8vo,	*2 00
—— Lessons in Telegraphy	12mo,	*1 00
Sewell, T. The Construction of Dynamos	8vo,	*3 00
Sexton, A. H. Fuel and Refractory Materials	12mo,	*2 50
—— Chemistry of the Materials of Engineering	12mo,	*2 50
—— Alloys (Non-Ferrous)	8vo,	*3 00
—— The Metallurgy of Iron and Steel	8vo,	*6 50
Seymour, A. Modern Printing Inks	8vo,	*2 00
Shaw, Henry S. H. Mechanical Integrators. (Science Series No. 83.)	16mo,	0 50
Shaw, S. History of the Staffordshire Potteries	8vo,	2 00
—— Chemistry of Compounds Used in Porcelain Manufacture	8vo,	*5 00
Shaw, W. N. Forecasting Weather	8vo,	*3 50
Sheldon, S., and Hausmann, E. Direct Current Machines	12mo,	*2 50
—— Alternating Current Machines	12mo,	*2 50
Sheldon, S., and Hausmann, E. Electric Traction and Transmission Engineering	12mo,	*2 50
Shields, J. E. Notes on Engineering Construction	12mo,	1 50
Shreve, S. H. Strength of Bridges and Roofs	8vo,	3 50
Shunk, W. F. The Field Engineer	12mo, morocco,	2 50
Simmons, W. H., and Appleton, H. A. Handbook of Soap Manufacture,	8vo,	*3 00
Simmons, W. H., and Mitchell, C. A. Edible Fats and Oils	8vo,	*3 00
Simpson, G. The Naval Constructor	12mo, morocco,	*5 00
Simpson, W. Foundations	8vo. (*In Press.*)	
Sinclair, A. Development of the Locomotive Engine	8vo, half leather,	5 00
Sindall, R. W., and Bacon, W. N. The Testing of Wood Pulp	8vo,	*2 50
Sindall, R. W. Manufacture of Paper. (Westminster Series.)	8vo,	*2 00
Sloane, T. O'C. Elementary Electrical Calculations	12mo,	*2 00
Smallwood, J. C. Mechanical Laboratory Methods. (Van Nostrand's Textbooks.)	12mo, leather,	*2 50
Smith, C. A. M. Handbook of Testing, MATERIALS	8vo,	*2 50
Smith, C. A. M., and Warren, A. G. New Steam Tables	8vo,	*1 25
Smith, C. F. Practical Alternating Currents and Testing	8vo,	*2 50
—— Practical Testing of Dynamos and Motors	8vo,	*2 00
Smith, F. A. Railway Curves	12mo,	*1 00
—— Standard Turnouts on American Railroads	12mo,	*1 00
—— Maintenance of Way Standards	12mo,	*1 50
Smith, F. E. Handbook of General Instruction for Mechanics	12mo,	1 50
Smith, H. G. Minerals and the Microscope	12mo,	*1 25
Smith, J. C. Manufacture of Paint	8vo,	*3 50
Smith, R. H. Principles of Machine Work	12mo,	*3 00
—— Elements of Machine Work	12mo,	*2 00
Smith, W. Chemistry of Hat Manufacturing	12mo,	*3 00
Snell, A. T. Electric Motive Power	8vo,	*4 00
Snow, W. G. Pocketbook of Steam Heating and Ventilation. (*In Press.*)		

Snow, W. G., and Nolan, T. Ventilation of Buildings. (Science Series No. 5.)	16mo,	0 50
Soddy, F. Radioactivity	8vo,	*3 00
Solomon, M. Electric Lamps. (Westminster Series.)	8vo,	*2 00
Somerscales, A. N. Mechanics for Marine Engineers	12mo,	*1 50
—— Mechanical and Marine Engineering Science	8vo,	*5 00
Sothern, J. W. The Marine Steam Turbine	8vo,	*5 00
—— Verbal Notes and Sketches for Marine Engineers	8vo,	*5 00
Sothern, J. W., and Sothern, R. M. Elementary Mathematics for Marine Engineers	12mo,	*1 00
—— Simple Problems in Marine Engineering Design	12mo,	*1 00
Southcombe, J. E. Chemistry of the Oil Industries. (Outlines of Industrial Chemistry.)	8vo,	*3 00
Soxhlet, D. H. Dyeing and Staining Marble. Trans. by A. Morris and H. Robson	8vo,	*2 50
Spang, H. W. A Practical Treatise on Lightning Protection	12mo,	1 00
Spangenburg, L. Fatigue of Metals. Translated by S. H. Shreve. (Science Series No. 23.)	16mo,	0 50
Specht, G. J., Hardy, A. S., McMaster, J. B., and Walling. Topographical Surveying. (Science Series No. 72.)	16mo,	0 50
Spencer, A. S. Design of Steel-Framed Sheds	8vo,	*4 00
Speyers, C. L. Text-book of Physical Chemistry	8vo,	*2 25
Spiegel, L. Chemical Constitution and Physiological Action. (Trans. by C. Luedeking and A. C. Boylston.)		1 25
Sprague, E. H. Hydraulics	12mo,	1 25
Stahl, A. W. Transmission of Power. (Science Series No. 28.)	16mo,	
Stahl, A. W., and Woods, A. T. Elementary Mechanism	12mo,	*2 00
Staley, C., and Pierson, G. S. The Separate System of Sewerage	8vo,	*3 00
Standage, H. C. Leatherworkers' Manual	8vo,	*3 50
—— Sealing Waxes, Wafers, and Other Adhesives	8vo,	*2 00
—— Agglutinants of all Kinds for all Purposes	12mo,	*3 50
Stanley, H. Practical Applied Physics	(*In Press.*)	
Stansbie, J. H. Iron and Steel. (Westminster Series.)	8vo,	*2 00
Steadman, F. M. Unit Photography	12mo,	*2 00
Stecher, G. E. Cork. Its Origin and Industrial Uses	12mo,	1 00
Steinman, D. B. Suspension Bridges and Cantilevers. (Science Series No. 127.)		0 50
—— Melan's Steel Arches and Suspension Bridges	8vo,	*3 00
Stevens, H. P. Paper Mill Chemist	16mo,	*2 50
Stevens, J. S. Theory of Measurements	12mo,	*1 25
Stevenson, J. L. Blast-Furnace Calculations	12mo, leather,	*2 00
Stewart, G. Modern Steam Traps	12mo,	*1 25
Stiles, A. Tables for Field Engineers	12mo,	1 00
Stodola, A. Steam Turbines. Trans. by L. C. Loewenstein	8vo,	*5 00
Stone, H. The Timbers of Commerce	8vo,	3 50
Stopes, M. Ancient Plants	8vo,	*2 00
—— The Study of Plant Life	8vo,	*2 00
Stumpf, Prof. Una-Flow of Steam Engine	4to,	*3 50
Sudborough, J. J., and James, T. C. Practical Organic Chemistry	12mo,	*2 00
Suffling, E. R. Treatise on the Art of Glass Painting	8vo,	*3 50
Sur, F. J. S. Oil Prospecting and Extracting	8vo,	*1 00

Swan, K. **Patents, Designs and Trade Marks.** (Westminster Series.).	8vo,	*2 00
Swinburne, J., Wordingham, C. H., and Martin, T. C. **Electric Currents.** (Science Series No. 109.)	16mo,	0 50
Swoope, C. W. **Lessons in Practical Electricity**	12mo,	*2 00
Tailfer, L. **Bleaching Linen and Cotton Yarn and Fabrics**	8vo,	*5 00
Tate, J. S. **Surcharged and Different Forms of Retaining-walls.** (Science Series No. 7.)	16mo,	0 50
Taylor, F. N. **Small Water Supplies**	12mo,	*2 00
—— **Masonry in Civil Engineering**	8vo,	*2 50
Taylor, T. U. **Surveyor's Handbook**	12mo, leather,	*2 00
—— **Backbone of Perspective**	12mo,	*1 00
Taylor, W. P. **Practical Cement Testing**	8vo,	*3 00
Templeton, W. **Practical Mechanic's Workshop Companion.**	12mo, morocco,	2 00
Tenney, E. H. **Test Methods for Steam Power Plants.** (Van Nostrand's Textbooks.)	12mo,	*2 50
Terry, H. L. **India Rubber and its Manufacture.** (Westminster Series.)	8vo,	*2 00
Thayer, H. R. **Structural Design.** 8vo.		
Vol. I. **Elements of Structural Design**		*2 00
Vol. II. **Design of Simple Structures**		*4 00
Vol. III. **Design of Advanced Structures**	*(In Preparation.)*	
—— **Foundations and Masonry**	*(In Preparation.)*	
Thiess, J. B., and Joy, G. A. **Toll Telephone Practice**	8vo,	*3 50
Thom, C., and Jones, W. H. **Telegraphic Connections**	oblong, 12mo,	1 50
Thomas, C. W. **Paper-makers' Handbook**	*(In Press.)*	
Thompson, A. B. **Oil Fields of Russia**	4to,	*7 50
Thompson, S. P. **Dynamo Electric Machines.** (Science Series No. 75.)	16mo,	0 50
Thompson, W. P. **Handbook of Patent Law of All Countries**	16mo,	1 50
Thomson, G. S. **Milk and Cream Testing**	12mo,	*1 75
—— **Modern Sanitary Engineering, House Drainage, etc**	8vo,	*3 00
Thornley, T. **Cotton Combing Machines**	8vo,	*3 00
—— **Cotton Waste**	8vo,	*3 00
—— **Cotton Spinning.** 8vo.		
First Year		*1 50
Second Year		*3 00
Third Year		*2 50
Thurso, J. W. **Modern Turbine Practice**	8vo,	*4 00
Tidy, C. Meymott. **Treatment of Sewage.** (Science Series No. 94.)	16mo,	0 50
Tillmans, J. **Water Purification and Sewage Disposal.** Trans. by Hugh S. Taylor	8vo,	*2 00
Tinney, W. H. **Gold-mining Machinery**	8vo,	*3 00
Titherley, A. W. **Laboratory Course of Organic Chemistry**	8vo,	*2 00
Toch, M. **Chemistry and Technology of Paints**	8vo,	*4 00
—— **Materials for Permanent Painting**	12mo,	*2 00
—— **Chemistry and Technology of Mixed Paints**	*(In Press.)*	
Tod, J., and McGibbon, W. C. **Marine Engineers' Board of Trade Examinations**	8vo,	*1 50

Todd, J., and Whall, W. B. Practical Seamanship 8vo, *7 50

Tonge, J. Coal. (Westminster Series.) 8vo, *2 00

Townsend, F. Alternating Current Engineering .... 8vo, boards, *0 75

Townsend, J. Ionization of Gases by Collision 8vo, *1 25

Transactions of the American Institute of Chemical Engineers, 8vo.
Seven volumes now ready. Vol. I. to VII., 1908-1914 .... 8vo, each, *6 00

Traverse Tables. (Science Series No. 115.) 16mo, 0 50
morocco, 1 00

Treiber, E. Foundry Machinery. Trans. by C. Salter 12mo, 1 25

Trinks, W., and Housum, C. Shaft Governors. (Science Series No. 122.)
16mo, 0 50

Trowbridge, W. P. Turbine Wheels. (Science Series No. 44.) .. 16mo, 0 50

Tucker, J. H. A Manual of Sugar Analysis 8vo, 3 50

Tunner, P. A. Treatise on Roll-turning. Trans. by J. B. Pearse.
8vo, text and folio atlas, 10 00

Turnbull, Jr., J., and Robinson, S. W. A Treatise on the Compound Steam-engine. (Science Series No. 8.) 16mo,

Turrill, S. M. Elementary Course in Perspective 12mo, *1 25

Twyford, H. B. Purchasing 8vo, *3 00

Tyrrell, H. G. Design and Construction of Mill Buildings 8vo, *4 00

—— Concrete Bridges and Culverts .... 16mo, leather, *3 00

—— Artistic Bridge Design 8vo, *3 00

Underhill, C. R. Solenoids, Electromagnets and Electromagnetic Windings 12mo, *2 00

Underwood, N., and Sullivan, T. V. Chemistry and Technology of Printing Inks 8vo, *3 00

Urquhart, J. W. Electric Light Fitting 12mo, 2 00

—— Electro-plating 12mo, 2 00

—— Electrotyping 12mo, 2 00

Usborne, P. O. G. Design of Simple Steel Bridges 8vo, *4 00

Vacher, F. Food Inspector's Handbook 12mo, *3 00

Van Nostrand's Chemical Annual. Third issue 1913 .... leather, 12mo, *2 50

—— Year Book of Mechanical Engineering Data .... (*In Press.*)

Van Wagenen, T. F. Manual of Hydraulic Mining 16mo, 1 00

Vega, Baron Von. Logarithmic Tables .... 8vo, cloth, 2 00
half morroco, 2 50

Vincent, C. Ammonia and its Compounds. Trans. by M. J. Salter . 8vo, *2 00

Volk, C. Haulage and Winding Appliances 8vo, *4 00

Von Georgievics, G. Chemical Technology of Textile Fibres. Trans. by C. Salter 8vo, *4 50

—— Chemistry of Dyestuffs. Trans. by C. Salter 8vo, *4 50

Vose, G. L. Graphic Method for Solving Certain Questions in Arithmetic and Algebra (Science Series No. 16.) 16mo, 0 50

Vosmaer, A. Ozone .... (*In Press.*)

Wabner, R. Ventilation in Mines. Trans. by C. Salter 8vo, *4 50

Wade, E. J. Secondary Batteries 8vo, *4 00

Wadmore, T. M. Elementary Chemical Theory	12mo,	*1 50
Wadsworth, C. Primary Battery Ignition	12mo,	*0 50
Wagner, E. Preserving Fruits, Vegetables, and Meat	12mo,	*2 50
Waldram, P. J. Principles of Structural Mechanics	12mo,	*3 00
Walker, F. Aerial Navigation	8vo,	2 00
—— Dynamo Building. (Science Series No. 98.)	16mo,	0 50
Walker, F. Electric Lighting for Marine Engineers	8vo,	2 00
Walker, J. Organic Chemistry for Students of Medicine	8vo,	*2 50
Walker, S. F. Steam Boilers, Engines and Turbines	8vo,	3 00
—— Refrigeration, Heating and Ventilation on Shipboard	12mo,	*2 00
—— Electricity in Mining	8vo,	*3 50
Wallis-Tayler, A. J. Bearings and Lubrication	8vo,	*1 50
—— Aerial or Wire Ropeways	8vo,	*3 00
—— Motor Vehicles for Business Purposes	8vo,	3 50
—— Refrigeration, Cold Storage and Ice-Making	8vo,	*4 50
—— Sugar Machinery	12mo,	*2 00
Walsh, J. J. Chemistry and Physics of Mining and Mine Ventilation,	12mo,	*2 00
Wanklyn, J. A. Water Analysis	12mo,	2 00
Wansbrough, W. D. The A B C of the Differential Calculus	12mo,	*1 50
—— Slide Valves	12mo,	*2 00
Waring, Jr., G. E. Sanitary Conditions. (Science Series No. 31.)	16mo,	0 50
—— Sewerage and Land Drainage		*6 00
Waring, Jr., G. E. Modern Methods of Sewage Disposal	12mo,	2 00
—— How to Drain a House	12mo,	1 25
Warnes, A. R. Coal Tar Distillation	8vo,	*2 50
Warren, F. D. Handbook on Reinforced Concrete	12mo,	*2 50
Watkins, A. Photography. (Westminster Series.)	8vo,	*2 00
Watson, E. P. Small Engines and Boilers	12mo,	1 25
Watt, A. Electro-plating and Electro-refining of Metals	8vo,	*4 50
—— Electro-metallurgy	12mo,	1 00
—— The Art of Soap Making	8vo,	3 00
—— Leather Manufacture	8vo,	*4 00
—— Paper-Making	8vo,	3 00
Weather and Weather Instruments	12mo,	1 00
	paper,	0 50
Webb, H. L. Guide to the Testing of Insulated Wires and Cables	12mo,	1 00
Webber, W. H. Y. Town Gas. (Westminster Series.)	8vo,	*2 00
Weisbach, J. A Manual of Theoretical Mechanics	8vo,	*6 00
	sheep,	*7 50
Weisbach, J., and Herrmann, G. Mechanics of Air Machinery	8vo,	*3 75
Welch, W. Correct Lettering	*(In Press.)*	
Wells, M. B. Steel Bridge Designing	8vo,	*2 50
Weston, E. B. Loss of Head Due to Friction of Water in Pipes	12mo,	*1 50
Weymouth, F. M. Drum Armatures and Commutators	8vo,	*3 00
Wheatley, O. Ornamental Cement Work	8vo,	*2 00
Wheeler, J. B. Art of War	12mo,	1 75
—— Field Fortifications	12mo,	1 75